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## WETLANDS AND WATERBIRDS OF THE SNOWY RIVER AND GIPPSLAND LAKES CATCHMENT

By A. H. CORRICK\* AND F. I. NORMAN\*

**ABSTRACT:** Wetlands in the Snowy River and Gippsland Lakes catchments were located and categorized using water regimes and salinity; subcategories were determined using differences in vegetation. Fifteen categories and subcategories were recognised within 72,205 ha of wetland surveyed; the study area also contained an additional 32,522 ha of river flats. Most waterbird habitat (68,492 ha, 95%) was contained in 53 wetlands, each larger than 100 ha. Permanent saline wetlands were most extensive (24,766 ha) but open waters of deep freshwater marshes supported more birds, and more species of birds, than other categories. Of the estimated original wetland area (112,265 ha) 7% has been eliminated, and a further 29% (mainly river flats) has been greatly modified since settlement. Drainage and flood control works have been responsible for most alteration. We conclude that reservation of further wetlands is essential if the waterbird resource is to be maintained. Modification of existing areas may also affect nomadic and migratory species originating elsewhere.

### INTRODUCTION

Australia is essentially a dry continent and has, over much of its land surface, an unreliable rainfall with varying annual patterns of distribution. Nevertheless, wetlands (areas temporarily or permanently inundated) of varying types have developed and many bird species have adapted to use such habitats for feeding, resting or breeding. Conservation of these dependent species implies preservation of appropriate habitats and presupposes an adequate knowledge of their habitat requirements. In Australia few attempts have been made to determine the various types and the area of wetlands used by the various species of waterbirds. (Whilst many species of birds use wetlands, waterbirds in this context include members of the following families: Podicipedidae, Pelecanidae, Anhingidae, Phalacrocoracidae, Ardeidae, Ciconiidae, Platealeidae, Anatidae, Accipitridae, Rallidae, Gruidae, Rostratulidae, Haematopodidae, Charadriidae, Recurvirostridae, Scolopacidae and Laridae.) Studies by Corrick and Cowling (1975), Goodrick (1970), Lavery (1966) and Riggert (1966) are the only surveys of Australian wetlands, and these deal with only relatively small areas. Since many Australian waterbirds are nomadic and use widely separated habitats, additional surveys of more extensive areas are required.

In this paper we present results obtained in the first of a series of surveys designed to provide data on the distribution, water regime, vegetation and abun-

dance of Victorian wetlands, and their utilization by waterbirds.

### STUDY AREA

The study area (Fig. 1) is approximately 27,000 km<sup>2</sup>, about 10 % of the area of Victoria. Most lowlands in the area, except regions of poor soil between Lakes Entrance and the Snowy River and deep sands between Stratford and Bairnsdale and south of Sale, are farmed. Even so the population is essentially urban and concentrated in the brown coalfield towns of Moe and Yallourn (population 21,000), Morwell (17,000), and Traralgon (15,000). Rural towns are considerably smaller (e.g. Sale 10,000, Bairnsdale 8500, Warragul 7000, Maffra 3600; data from Bowden 1977).

### PHYSIOGRAPHY

Hills (1964) considered that the study area contained three main physiographic divisions, each with a characteristic topography and hence different types of wetland. The Eastern Highlands, an eroded plateau of a Mesozoic peneplain, has steep ridges and narrow valleys. The poor soils support *Eucalyptus* forests, though these have been mostly cleared from alluvial flats. The second division, the South Gippsland Highlands, occupies the southwestern portion of the study area and is an upwarped, faulted and eroded area of Cainozoic sand and mud stones capped in part by basalts. Dissection is mature and deep, and the steep

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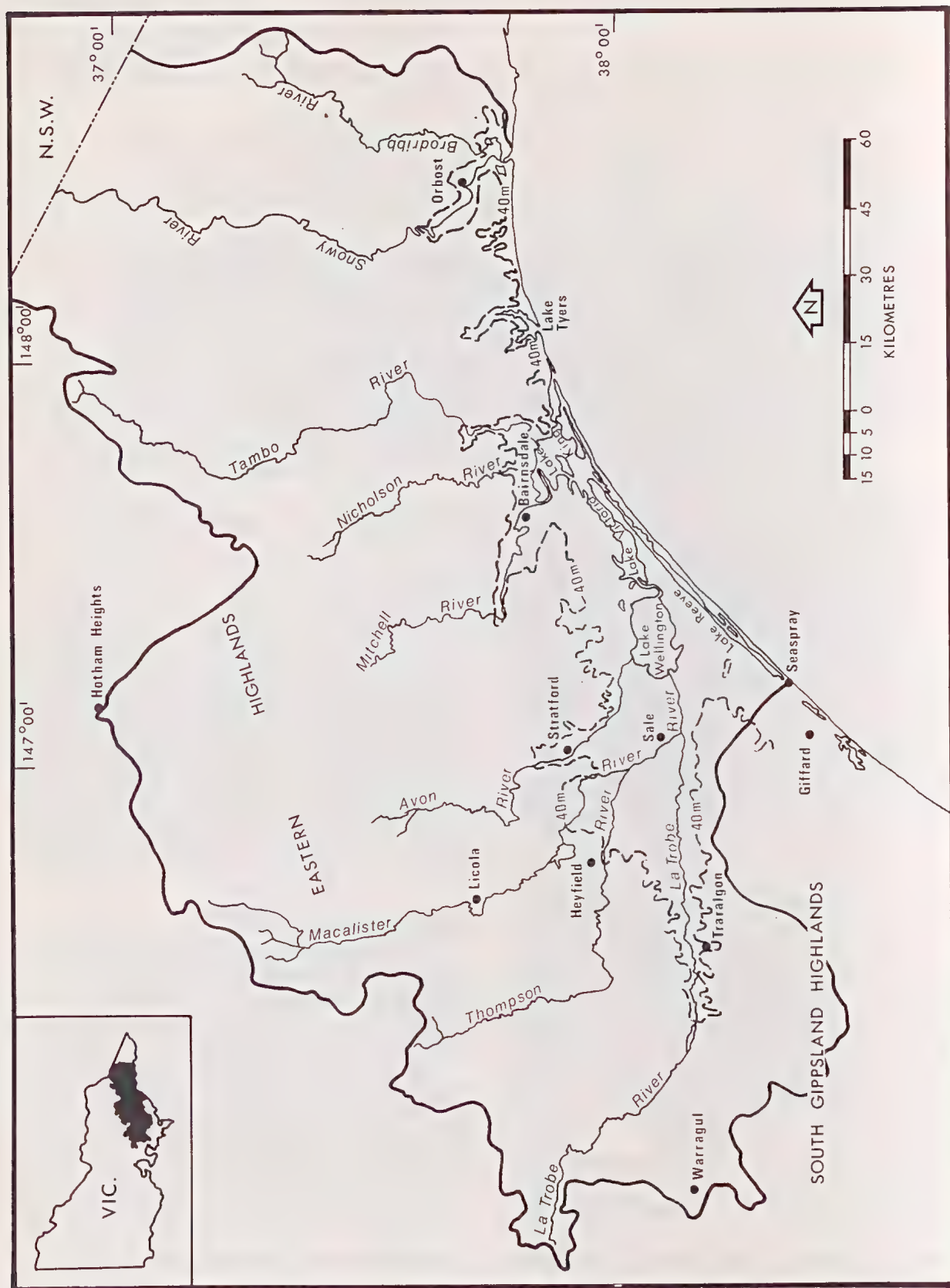


Fig. 1. The study area. The 40 metre contour delimits the East Gippsland Plains.



slopes are rounded. Streams flow within narrow valleys until they reach the third physiographic division, the East Gippsland Plains. Cainozoic sediments overlain by fluvial sands and gravels and sands of marine origin form the Plains, which extend along the southern edge of the study area (Fig. 1). Lagoons and tidal lakes have formed along the coast.

The river flats within the Plains are composed of two sections, meander and delta plains (Jenkin 1968). On the meander plains, swamps formed within cut-off meanders range in size from small, simple oxbows to continuous lengths of by-passed stream beds filled only in floods. In contrast, delta plains formed as river deltas with associated natural levees advance into drowned valleys and shallow bays. The extensive swamps formed behind the levees at the mouths of most rivers in the study area (i.e. LaTrobe, Avon, Mitchell, Tambo and Snowy Rivers) represent a major wetland formation within the area.

The other major formation, coastal lagoons, were formed by sand bars enclosing shallow bays and by vegetation which stabilized silt deposited by inflowing rivers (e.g. Bird 1962, 1965 a, b, Jenkin 1968, Nicholson 1972). Elsewhere, and particularly within the Dividing Range, wetlands are restricted to small areas of river flats and infrequent water storages.

## CLIMATE

Climatic details for part or all of the study area are available (e.g. Bureau of Meteorology 1975, 1976; Central Planning Authority 1954, 1968; Land Conservation Council 1972; Nicholson 1972) but only rainfall and the negative effects of temperature and evaporation on subsequent run-off will be discussed further.

Rainfall is evenly distributed throughout the year, increasing with elevation and from east to west across the study area (e.g. Hotham Heights 1538 mm p.a., Orbost 839 mm p.a. and Warragul 1051 mm p.a.) although stations in the deeper river valleys and near Sale are affected by rain shadows (e.g. Seaspray 585 mm p.a. and Licola 741 mm p.a.; Bureau of Meteorology 1975). Temperatures are warm to hot during summer and cool during winter and are moderated by proximity to the sea and by increasing and decreasing altitude respectively (e.g. mean maximum and minimum daily temperatures for January at Sale are 25.9 and 12.9°C, Hotham Heights 17.6 and 7.5°C and Orbost 25.4 and 13.1°C and for July at Sale 13.5 and 3.3°C, Hotham Heights 1.2 and -3.3°C and Orbost 14.7 and 4.4°C; Bureau of Meteorology 1975).

Although few records are available evaporation ranges between 0.76 and 1.0 m, except in the upper Eastern Highlands, where losses are less than 0.76 m

(Bureau of Meteorology 1968). Seasonal differences in temperature and rainfall result in evaporation which exceeds rainfall by 3-4 times during summer, but is equal to or less than rainfall during winter (Bureau of Meteorology 1976). The resulting runoff varies from 25 mm near Sale to about 1 m in the Highlands (Department of National Development 1966).

Droughts are infrequent. For example, droughts of two months or more occur in less than 2% of winters. Droughts of two months or more starting in January are more common (i.e. Giffard 40% of all years, Orbost 16%) but prolonged droughts (of 5 months or more) are less frequent (Giffard 7%, Orbost 1%; Central Planning Authority 1954, 1968; Nicholson 1972). Thus the wetlands throughout the study area are reliably supplied with water.

## HYDROLOGY

More than 90% of the water discharged by rivers in the study area flows through the LaTrobe, Thomson, Macalister, Mitchell and Snowy Rivers. Flows are at a maximum during late winter and early spring, decrease as summer approaches and increase again after autumn and winter rains. Floods usually occur between June and October.

The water levels and salinity of the Gippsland Lakes are determined by rainfall, freshwater inflow and exchange of sea water with Bass Strait. The water level is highest, and the water freshest, during winter and spring, but during summer the water becomes increasingly saline and salt water may intrude as far as Lake Wellington (Ducker *et al.* 1977).

River flows are modified by diversion of water for various purposes. Diversions for irrigation from the Macalister and Thomson Rivers total 236,000 Ml per year, about 40% of the mean annual flow in the Macalister River, and since only 20% of diverted water returns to the river system (Melbourne and Metropolitan Board of Works 1975) wetlands dependent on river flows are inevitably affected. Additional water is taken for domestic and industrial purposes, mainly in the LaTrobe Valley (219,000 Ml p.a.), for private irrigation along river flats (60,000 Ml p.a., Ministry for Conservation 1977), and for hydro-electricity generation and irrigation from the upper Snowy River (20% of mean annual flow; Webster and McLennan 1965).

Some wetlands may be maintained or modified by ground water. However, the mechanism is not understood. Harris (1976), who summarised available data, indicated possible problems resulting from increased run-off as a result of changing land-use, from lowering of water tables and from pollution of the aquifers.



## METHODS

## WETLAND DISTRIBUTION

Wetlands were located from aerial photographs, from topographic maps\* or during ground surveys. Each wetland was examined, the water regime was determined and major plant communities identified and delineated on aerial photographs. Photographic enlargements were made, where appropriate, to help determine areas covered by wetlands and associated communities.

Drained wetlands were generally difficult to locate, particularly in agricultural areas where clearing and cultivation has been extensive. The boundaries of some former wetlands were determined from early maps or photographs. The detailed and extensive river flat surveys (State Rivers and Water Supply Commission 1934-40) showing contour levels and the proliferation of minor drains indicate many original basins. Whilst our survey provided evidence of many former wetlands some smaller drained areas were probably not located.

## WETLAND CLASSIFICATION

Several schemes of wetland classifications have been proposed (e.g. Martin *et al.* 1953, Cowardin & Johnson 1973) and local systems for specific areas varying both in size and complexity have been developed (e.g. Frith 1959, Lavery 1966, Riggert 1966, Goodrick 1970, Braithwaite 1975, Corrick & Cowling 1975). Such systems took account of combinations of water regime, salinity, plant species and their abundance and cover, and ratios of emergent vegetation to open water. Most classifications recognise problems associated with the variety of water regimes, and the physical and chemical factors which may occur. However, wetlands have usually been classified by the predominant plant community, even though small, less abundant communities may be more important to the ecology of waterbirds using the wetlands.

In this study wetlands were assigned to categories, based on their water regimes and salinity and subcategories were established using vegetational differences. These categories and subcategories are:—

1. *Flooded River Flats*
2. *Freshwater Meadows*
3. *Shallow Freshwater Marshes*
  - 3.1 *Herb-dominated*
  - 3.2 *Sedge-dominated*
4. *Deep Freshwater Marshes*
  - 4.1 *Shrub-dominated*

- 4.2 *Reed-dominated*
- 4.3 *Sedge-dominated*
- 4.4 *Rush-dominated*
- 4.5 *Open water*

5. *Permanent Open Freshwater*
6. *Semipermanent Saline Wetlands*
  - 6.1 *Salt pans*
  - 6.2 *Salt meadows*
  - 6.3 *Salt flats*
  - 6.4 *Sea rush-dominated*
7. *Permanent Saline Wetlands*
  - 7.1 *Shallow*
  - 7.2 *Deep*

CATEGORY 1. *Flooded River Flats*

Included in this category is land temporarily inundated for very short periods after flooding or heavy rain. Inundation is too brief to induce and support true aquatic vegetation, and plant species are determined by agricultural practices.

CATEGORY 2. *Freshwater Meadows*

Wetlands in this category have water-logged soil for up to 3 months each year, but surface water is usually shallow (< 0.2 m) and transient (< 14 days). The plant community which develops is dominated by *Carex appressa* and *Juncus* sp. but other species (e.g. *Paspalum distichum*, *Eleocharis acuta*, *Scirpus fluviatilis*, *Polygonum minus* and *Amphibromus neesii*) may be associated. This vegetation is modified by trampling and grazing by stock, which reduces herbs, and by cultivation which can eliminate tussocks.

CATEGORY 3. *Shallow Freshwater Marshes*

In these wetlands soil is water-logged throughout the year and surface water (< 0.5 m) may be present for 6-8 months. These marshes are usually dry by January and fill in May or June following rains or floods. Two subcategories are recognised:—

Subcategory 3.1 *Herb-dominated*

This subcategory of shallow freshwater marsh occurs on agricultural land. The annual, moist-soil species of plants are succeeded by pasture species as waters recede. Such marshes are typified by a diverse flora which includes *Marsilea mutica*, *Azolla filiculoides*, *Carex appressa*, *C. gaudichaudiana*, *Eleocharis acuta*, *Glyceria australis*, *Paspalum distichum*, *Scirpus fluviatilis*, *Potamogeton tricarlinatus*, *Alisma plantago-aquatica*, *Spirodela oligorrhiza*, *Polygonum minus*, *Ranunculus* sp., *Lythrum hyssopifolium*, *Ludwigia peploides*, *Rumex bidens*, *Callitriche stagnalis* and *Cotula coronopifolia*.

Subcategory 3.2 *Sedge-dominated*

This subcategory is typified by a dense cover of *Lepidosperma longitudinale*, *Cladium articulatum* and *Lepyrodi muelleri*; *Villarsia reniformis*, *Utricularia dichotoma* and *Selaginella uliginosa* may also occur.

\*Details of photographs and maps used, and locations of individual wetlands are available from the Librarian, Fisheries and Wildlife Division.



CATEGORY 4. *Deep Freshwater Marshes*

Deep freshwater marshes (> 1 m) remain undated during years of average or above average rainfall. Five subcategories are recognised:—

Subcategory 4.1 *Shrub-dominated*

Some areas of deep freshwater marshes are dominated by *Melaleuca ericifolia* whose multiple trunks may be 5 m high. The rootstocks collect soil and litter in which *Phragmites australis*, *Polygonum lapathifolium*, *Cotula coronopifolia* and *Urtica incisa* may grow. In deep water floating plants (e.g. *Azolla pinnata*, *Lemna minor*, etc.) may form dense mats, and submerged *Vallisneria spiralis* occurs. Emergent species (e.g. *Myriophyllum propinquum*, *Villarsia reniformis*, *Ranunculus* sp.) are common in shallower waters.

Subcategory 4.2 *Reed-dominated*

Areas of some deep freshwater marshes are dominated by tall, dense stands of *Phragmites australis*, *Juncus ingens* or *Typha* sp. in which few associated species grow.

Subcategory 4.3 *Sedge-dominated*

Small deep marshes, usually in dune swales, covered by *Lepidosperma longitudinale* are included in this subcategory. Associated species are usually few (mainly *Villarsia reniformis*, *V. exaltata*, *Utricularia dichotoma* and *U. australis*) but some (e.g. *Spirodela oligorrhiza*, *Azolla filiculoides*, *Eleocharis sphacelata*, *Myriophyllum propinquum*, *Potamogeton tricarlinatus*, *P. ochreatus*, *Vallisneria spiralis*, *Callitriche stagnalis* and algae) are more numerous in larger marshes.

Subcategory 4.4 *Rush-dominated*

*Eleocharis sphacelata* dominates some parts of deep freshwater marshes. Associated species include *Myriophyllum propinquum*, *Pseudoraphis paradoxa*, *Amphibromus neesii*, *Otelia ovalifolia*, *Villarsia reniformis*, *Potamogeton tricarlinatus*, *P. ochreatus*, *Ceratophyllum demersum*, *Ranunculus* sp., *Lemna trisulca*, *Azolla filiculoides*, *A. pinnata*, and *Spirodela oligorrhiza*.

Subcategory 4.5 *Open water*

Areas of open water devoid of emergent vegetation occur within deep freshwater marshes. The vegetation of the littoral margin includes *Cotula coronopifolia*, *Paspalum distichum*, *Scirpus fluviatilis*, *Eleocharis acuta*, *Triglochin procera* and *Potamogeton tricarlinatus*, but is much modified by changes in water levels, wave action, turbidity, gradient and grazing.

CATEGORY 5. *Permanent Open Freshwater*

Water storages and natural lakes deeper than 1 m are included in this category. Fluctuations of water-level in storages, together with the generally steep shoreline, restrict the growth of aquatic plants along the shore. In natural lakes *Vallisneria spiralis*, *Potamogeton ochreatus* and *Lepilaena bilocularis* are found in shallows where turbidity is low.

CATEGORY 6. *Semipermanent Saline Wetlands*

These wetlands are maintained by rainfall and inflows from permanent saline wetlands. Plant associations vary with the periodicity of inundation and four subcategories were distinguished:—

Subcategory 6.1 *Salt pans*

Generally salt pans have little surface water (< 0.5 m) except after winter and spring run-offs or floods. Some aquatic plants (e.g. *Lepilaena cylindrocarpa*, *L. preissii* and *Ruppia maritima*) are abundant in shallow waters during winter and spring but increasing salinity and temperatures, coupled with decreasing waterlevels, eliminate them during summer.

Subcategory 6.2 *Salt meadows*

Salt meadows are inundated for 3-5 months but are usually dry by January. Such areas are typified by a low ground-cover of *Salicornia quinqueflora* and *Mimulus repens*, and *L. preissii* may occur in the shallows. In grazed areas prostrate species may be reduced by trampling.

Subcategory 6.3 *Salt flats*

Salt flats have surface water only during winter and early spring. Vegetation is low, dense and varied in open areas and usually includes *Wilsonia humilis*, *W. backhousei*, *Salicornia quinqueflora*, *Samolus repens*, *Arthrocnemum halocnemoides*, *Distichlis distichophylla*, *Sporobolus virginicus*, *Monerma cylindrica*, *Frankenia pauciflora*, and *Selliera radicans*. Where beds of *Gahnia filum* develop, associated species are fewer.

Subcategory 6.4 *Sea rush-dominated*

Extensive stands of *Juncus maritimus* occur in some salt-affected areas inundated or water-logged for long periods. Such stands, which may occur in areas where *Melaleuca ericifolia* has died after salt intrusion, generally exclude other vegetation.

CATEGORY 7. *Permanent Saline Wetlands*

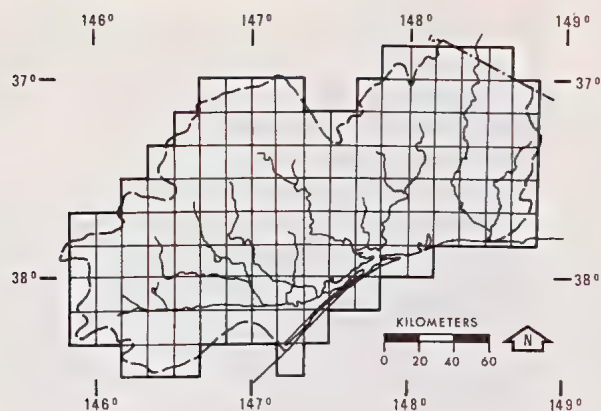
The entrances to most coastal lagoons in the study area are closed, or restricted for most of the year. Tidal influence is restricted or absent, and therefore the presence of shallow water determines waterbird usage. Two subcategories are recognised purely on water depth.

Subcategory 7.1 *Shallow*

*Zostera* sp., *Ruppia maritima* and algae (Ducker *et al.* 1977) are common in these shallow (< 2 m) areas. Shorelines are sandy or rock-covered, but *Juncus maritimus* may grow in more sheltered locations.

Subcategory 7.2 *Deep*

The subcategory includes deeper (> 2 m) waters which may support *Ruppia maritima*, *Zostera* sp. and algae depending on the turbidity and depth of water.



Freshwater meadow 2.



Shallow freshwater marshes 3.1 Herb dominated



Shallow freshwater marshes 3.2 Sedge-dominated



Deep freshwater marshes 4.1 Shrub-dominated



Deep freshwater marshes 4.2 Reed-dominated



Hectares

- ▲ < 25
- 25 - 150
- ◆ 150 - 500
- > 500

Fig. 2. The distribution (plotted on a 10' grid) of the area (ha) of each wetland category and subcategory of the study area.



Deep freshwater marshes 4.3 Sedge-dominated



Deep freshwater marshes 4.4 Rush-dominated



Deep freshwater marshes 5.5 Open water



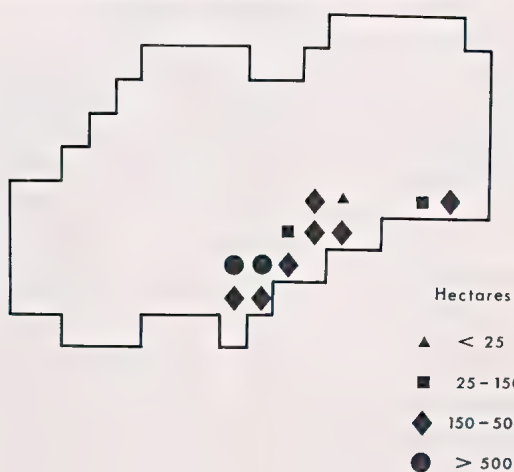
Permanent open freshwater 5.



Semipermanent saline wetlands 6.1 Salt pans



Semipermanent saline wetlands 6.2 Salt meadows



Hectares

- ▲ < 25
- 25 - 150
- ◆ 150 - 500
- > 500

Fig. 2 (continued)

Semipermanent saline wetlands 6.3 Salt flats



Semipermanent saline wetlands 6.4 Sea rush-dominated



Permanent saline wetlands 7.1 Shallow



Permanent saline wetlands 7.2 Deep



Hectares  
 ▲ < 25  
 ■ 25-150  
 ◆ 150-500  
 ● > 500

Fig. 2 (continued)

## WETLAND USAGE BY WATERBIRDS

Data on past and present distribution and abundance of waterbirds were obtained from the literature, lists supplied by local observers and observations made during the survey. Four-weekly counts were conducted at sites selected at the start of the study as being representative of major waterbird habitats in the area. These sites were in areas most used by non-breeding waterbirds and also included areas of cleared river flats, agricultural land and ocean beach; salt meadow and deep permanent saline wetlands were not surveyed. Four sites (66 ha) and one site (33 ha) of open and rush-dominated subcategories of deep freshwater marshes were sampled as were one site (135 ha) of permanent open freshwater, four sites (174 ha) of salt pan and six sites (757 ha) of shallow permanent saline wetland. Roadside counts were also made over 1880 ha of river flats and 2554 ha of agricultural land between Sale and Traralgon. Counts were made at the same time of day on each visit, using binoculars and

telescope. No doubt biases are inherent in this method (e.g. McClure 1945, Diem & Lu 1960, Eberhardt 1968) but it satisfied requirements for obtaining data on relative differences in abundance and usage.

## ANALYSIS OF WATERFOWL BANDING DATA

Waterfowl have been banded in Victoria since 1951 (McNally & Falconer 1953, Norman 1973). Most (81%) have been banded at Serendip (38°01'S 144°25'E) and only 1.8% have been banded within the study area. During hunting seasons banded birds are recovered throughout Australia. The number of recoveries within the study area is compared with those from elsewhere and the distribution of recoveries in the study area, was plotted on a 10' grid of the area.

## RESULTS

### WETLAND DISTRIBUTION

Fig. 2, which summarises the distribution of wetlands in each category and subcategory in each 10'



square, emphasises the abundance of wetlands around the Gippsland Lakes, and the scarcity of wetlands in the mountainous Eastern and South Gippsland Highlands. Indeed, other than the rivers there are few wetlands upstream from the coastal plains. The restricted distributions of saline wetlands, found only around salt lakes or near the sea, and sedge-dominated deep freshwater marshes, which occur only between Stratford and Bairnsdale and south of Sale, is also evident.

The area and number of individual wetlands of each category examined during the survey are shown in Tables 1 and 2. Of 72,205 ha examined, 68,492 ha (95%) are within the 53 wetlands which exceed 100 ha; the remaining 3,713 ha is comprised of 167 small wetlands.

Drainage works have eliminated 27 wetlands (of 5,625 ha) and reduced the surface area of another 18 (by 1,913 ha). Deep freshwater marshes have been most affected; 7181 ha (34%) have been lost and 140,476 and 540 ha have been altered to freshwater meadow, shallow freshwater marshes and semi-permanent saline wetland respectively. The area of shallow freshwater marshes has been reduced by 329 ha (25% of original area) and 28 ha (< 1%) of semipermanent saline wetlands have also been lost.

In addition to individual wetlands, 32,522 ha of river flats occur in the study area distributed as follows: LaTrobe River, 8740; Thomson River, 5200; Macalister River, 8100; Mitchell River, 5340; Snowy River, 5142.

These river flats are flooded briefly each year but contain many small wetlands (not recorded individually) which provide valuable waterbird habitat. Since settlement, clearing, cultivation, flood control works and drain construction have all modified the habitats provided by the flats, particularly by reduction of the area and duration of inundation of shallow basins. All river flats along major rivers have been modified to the detriment of most waterbirds. Thus of the 112,265 ha of wetland, including river flats, which previously existed in the study area, 36% (40,060 ha) have been eliminated or greatly modified.

#### WETLAND USAGE BY WATERBIRDS

The waterbirds recorded in each wetland category and subcategory are listed in Appendix 1. The open waters of deep freshwater marshes and shallow permanent saline wetlands had the most diverse avifauna (55 and 53 species respectively) although shallow freshwater marshes and salt pans also provide habitat for 40 species. In contrast only 3 species used salt flats and 2 the rush-dominated semipermanent saline wetlands. Shallow freshwater marshes and the shrub and reed-dominated subcategories of deep freshwater are the most important breeding habitats.

Few species have been recorded breeding in saline wetland categories.

Table 3 summarises the data for 27 species of birds seen during the four-weekly counts in selected wetland habitats. These 27 species consist of the 10 most abundant from each habitat. The table shows the comparative usage by different species within each category and also compares the relative abundance of each species in each habitat. Open waters of deep freshwater marshes showed the highest usage (27.3 bird/ha/visit) but salt pans (12.4) and shallow permanent saline wetlands (5.4) were also important. In all surveyed habitats relatively few species (e.g. Coot, Black Swan, Grey Teal, Silver Gull, Crested Tern, Swamp Hen and ibis) accounted for most of the total usage. The importance of certain wetland habitats to particular species, e.g. Crested Grebe, White-necked Heron, Musk, Black and Mountain Duck, Chestnut Teal, Red-necked Stint, Red-capped Dotterel and Black Cormorant, is shown by the large proportion of their estimated numbers occurring there. Open areas of deep freshwater marshes were particularly important in that more than 40% of the estimated numbers of 8 of the 27 species listed in Table 3 used them.

Counts and observations were made on a variety of non-wetland habitats likely to be used by waterbirds. On agricultural land between Heyfield and Traralgon (Table 3) White and Straw-necked Ibis were more common than those species which fed in water (Coot and Black Swan). On cleared areas in the Eastern Highlands, where waterbird habitat was restricted to farm dams and river courses, Wood Duck, White-faced Heron and Masked Plover, which feed away from water, were most common; Little Grebe, Black Duck, Grey Teal and several species of cormorant were far less abundant. The numbers of waterbirds in the Highlands appeared to be much less than the totals of the same species occurring on large wetlands elsewhere. Along the coast waterbird usage of some sites is higher because of roosting or resting by birds which normally feed out to sea; at Lake Tyers Beach, for example, 75% of the usage was contributed by Silver Gull and Crested Tern (Table 3).

There was considerable seasonal variation in both the habitats used by many waterbirds, and their occurrence. Migratory species were present during summer (snipe, sandpipers, godwit, Eastern Curlew and Common Tern) or winter (Cattle Egret and Double-banded Dotterel). However, nomadic species (e.g. White-eyed Duck, Pink-eared Duck and Grey Teal) may be present at any time throughout the year. Of the species which breed in the study area only the Little Tern is known as a regular migrant (absent between February and September); other breeding species (e.g. Pied and Little Pied Cormorant, Royal Spoonbill,

TABLE 1.  
AREA OF WETLAND CATEGORIES AND SUBCATEGORIES IN EACH WETLAND SIZE RANGE  
(CATEGORY 1, RIVER FLATS, IS OMITTED).

Category/subcategory	Area (ha) in wetlands of the following size ranges:					Total area (ha)	
	<5	6-10	11-25	26-100	>100	Subcategory	Category
2 Freshwater meadow	10	25	46	177	104		362
3 Shallow freshwater marshes							
.1 Herb-dominated	16	47	166	143	581	953	988
.2 Sedge-dominated	19		16			35	
4 Deep freshwater marshes							13725
.1 Shrub-dominated		10	5		3108	3123	
.2 Reed-dominated			1	25	3769	3795	
.3 Sedge-dominated	181	166	242	179	46	814	
.4 Rush-dominated	17	10	88	15	1422	1552	
.5 Open water	21	37	113	82	4188	4441	
5 Permanent open water			34		16880		16914
6 Semipermanent saline wetlands							15450
.1 Salt pans	7	18	94	387	5220	5726	
.2 Salt meadows	41	29	198	570	5534	6372	
.3 Salt flats	4	32	120	179	2771	3106	
.4 Sea rush-dominated			4	52	190	246	
7 Permanent saline wetlands							24766
.1 Shallow			42	45	9008	9095	
.2 Deep					15671	15671	
Total area :	316	374	1169	1854	68492		72205



TABLE 2.  
NUMBER OF WETLAND CATEGORIES AND SUBCATEGORIES IN EACH WETLAND SIZE RANGE  
(CATEGORY 1, RIVER FLATS, IS OMITTED).

Category/subcategory	Number in wetlands of the following size (ha) ranges					Total number	
	< 5	6-10	11-25	26-100	>100	Subcategory	Category
2 Freshwater meadow	2	3	2	3	1		11
3 Shallow freshwater marshes							
.1 Herb-dominated	5	7	8	3	2	25	
.2 Sedge-dominated	7		1			8	
Number of wetlands	12	7	9	3	2		33
4 Deep freshwater marshes							
.1 Shrub-dominated		1	2		13	16	
.2 Reed-dominated			1	1	13	15	
.3 Sedge-dominated	66	24	15	4	1	110	
.4 Rush-dominated	6	2	7	1	2	18	
.5 Open water	8	5	8	4	15	40	
Number of wetlands	75	30	25	7	17		154
5 Permanent open water			2		5		7
6 Semipermanent saline wetlands							
.1 Salt pan	4	3	8	20	14	49	
.2 Salt meadows	17	6	16	20	18	77	
.3 Salt flats	2	6	10	6	4	28	
.4 Sea rush-dominated			1	2	4	7	
Number of wetlands	19	12	26	26	20		103
7 Permanent saline wetlands							
.1 Shallow			3	1	8	12	
.2 Deep					6	6	
Number of wetlands			3	1	8		12
Total number	108	52	67	40	53		320

TABLE 3.  
THE OCCURRENCE AND PERCENTAGE ABUNDANCE INDICES OF WATERBIRDS RECORDED IN SELECTED HABITATS IN THE STUDY AREA. THE TEN MOST ABUNDANT SPECIES ON EACH HABITAT ARE INCLUDED.

Species	Occurrence <sup>a</sup> (and percentage abundance indices <sup>b</sup> ) of species recorded in:							
	Wetland category and subcategory					Other areas		
	4.4	4.5	5	6.1	7.2	River flats	Farmland	Beach
Great Crested Grebe								
Hoary-headed Grebe		2 (34)	7 (36)	*	(1)	2 (99)	1	*
Australian Pelican		*	1 (25)	1	(12)	2 (15)	1	*
Little Pied Cormorant	*	(*)		*	(23)	1 (15)	1	3
Black Cormorant		1 (24)	*	1	(17)	4 (53)	1	
Little Black Cormorant		*	*	*	(1)	5 (86)	2	1
White-necked Heron	4 (40)	*	1 (33)	*	(5)	1 (30)	*	*
White-faced Heron	8 (3)		*	*	(8)	*		
White Ibis		*	*	3	(77)	*	7	*
Straw-necked Ibis		1 (43)	1 (7)	*	(*)	*		*
Black Swan	45 (1)	*				24 (49)	26	
Mountain Duck		10 (26)	6 (4)	27	(38)	11 (88)	39	
Black Duck		1 (27)		5	(72)	5 (*)	10	
Grey Teal		7 (84)		2	(13)	1 (1)	*	
Chestnut Teal		17 (64)		16	(35)	3 (1)	1	
Musk Duck		2 (19)	*	10	(54)	7 (1)	*	
Swamp Harrier	3 (13)	*	1 (53)	*	(11)	*		
Dusky Moorhen		*	*	*	(*)	*		
Swamphen	35 (3)	3 (94)	*	*	(*)	5 (6)	1	
Coot		10 (97)	*	*	(1)	6 (2)	1	
Masked Plover		37 (46)	75 (23)	27	(18)	23 (1)	7	
Red-capped Dotterel		3 (82)	*	1	(12)	2 (2)	2	8
Red-necked Stint		*	(1)	1	(98)	*	*	1
Silver Gull		1 (13)	*	2	(100)	(*)		26
Pacific Gull				12	(74)	4 (13)		
Little Tern			2 (58)	*	(4)	5 (96)		3
Crested Tern			*	*	(15)	1 (27)		49
			*	*	(3)	1 (91)		
% of total usage	95	94	95	99	99	98	86	96
Additional species	1	15	7	8	13	15	9	14
Total all species (birds/ha/visit.)	0.6	27.3	1.8	12.4	5.4	1.8	0.6	6.5

a For each species, the number of individuals/ha/visit expressed as a percentage of the total number of individuals of all species/ha/visit for each habitat.

b For each species, the estimated number of individuals in a particular habitat (N) expressed as a percentage of the estimated number of individuals of that species on all the surveyed habitats. N is calculated as the average number of individuals/



ibis, Chestnut Teal and Wood Duck) may move throughout coastal south-eastern Australia or far inland on a less predictable basis, but probably in response to varying seasonal conditions.

#### ANALYSIS OF WATERFOWL BANDING DATA

The distribution of band recoveries, plotted on a 10' grid over the study area (Fig. 3), shows that Chestnut Teal were recovered from 25 10' grid squares, Black Duck from 31 and Grey Teal from 48. 45% of the Chestnut Teal recoveries came from wetlands close to Lakes Wellington and Victoria while only 21% of Black Duck and 27% of Grey Teal recoveries came from the same area. The importance of the study area to Chestnut Teal is shown by the higher proportion (32%) of recoveries of this species which have come from within the study area (c.f. Grey Teal 8% and Black Duck 12%, see Table 4).

#### DISCUSSION

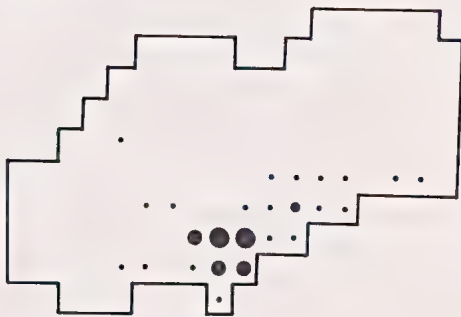
Coastal wetlands of southeastern Australia not only support local breeding populations of waterbirds but also provide drought refuges for species which breed inland, and non-breeding habitat for migratory species. The study area is of considerable importance to waterbirds since it contains almost as much wetland habitat (47,439 ha), within comparable categories, as does the entire coast of New South Wales (53,198 ha) (see Goodrick 1970). Nevertheless, our survey shows that the wetland area has so declined that of about 112,200 ha present during the early stages of settlement some 40,000 ha (36%) have been eliminated or greatly modified. This reduction is similar to those reported by Riggett (1966) and Goodrick (1970), who found a loss of some 32 and 38% of wetland habitat in study areas in the south of Western Australia and coastal New South Wales. Deep freshwater marshes have suffered most losses, and river flats have been greatly modified. Since existing deep freshwater marshes are of high value as breeding or feeding habitat, so presumably were those which have been lost. Changes in river flats, which before settlement were probably complex systems of shallow wetlands, *Melaleuca* thickets, and red gum woodland with deep cut-off lagoons, have been more difficult to evaluate. Modifications may have been detrimental to some species, but beneficial to others such as White Ibis, Wood Duck, White-faced Heron.

This study shows that some wetlands receive more usage than others but that most species use a variety of wetland types. Presumably such variation reflects the habitat requirements of individual species. Consequently further loss or modification of wetland habitat will affect many species of waterbirds, and future changes in land-use or water-diversion should

Black Duck



Chestnut Teal



Grey Teal



- 0-5
- 6-10
- 11-20
- 21+

KILOMETRES

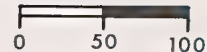


Fig. 3. The distribution (plotted on a 10' grid) of the recoveries of banded ducks shot in the study area during open seasons between 1953 and 1973. Only those species with more than 100 recoveries in the study area are shown.

TABLE 4.  
RECOVERIES, DURING OPEN SEASONS 1951-73, OF DUCKS Banded IN VICTORIA. THE SMALL  
NUMBER OF BIRDS Banded IN THE STUDY AREA ARE NOT INCLUDED IN THE TABLE.

	NUMBER Banded	NUMBER RECOVERED IN VICTORIA	STUDY AREA	(%)
Black Duck	6223	1168	137	(11.7)
Chestnut Teal	4056	484	156	(32.2)
Grey Teal	60491	8972	719	(8.0)
White-eyed Duck	420	27	2	(7.4)
Mountain Duck	3812	652	52	(8.0)
Wood Duck	1513	168	2	(1.2)

be based on the integration of requirements of waterbird populations with those of potentially conflicting interests. Industry, waste disposal, sewerage, irrigation and urban requirements already impinge on wetland water requirements, and pollutants may present additional hazards. Recreation (fishing, boating, hunting) place a demand on wetlands of various categories, and may not be compatible with the requirements of waterbirds.

Within the study area, only about 20% of the wetland areas are reserved as part of National Parks or State Wildlife Reserves. Whilst large areas of some categories such as salt pans and rush-dominated deep freshwater marshes are well represented, others, such as sedge-dominated deep freshwater marshes are not. Further reservation is required if the waterbird resource is to be retained. The modification of more wetland areas has implications not only locally within Victoria, but also within Australia, and for migratory species, far beyond. Further, although the emphasis of this study has been directed towards waterbirds and their use of wetlands of varying categories, this is not to deny the wider intrinsic value of wetlands as ecosystems worthy of preservation in their own right.

#### ACKNOWLEDGMENTS

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APPENDIX 1.

Waterbirds recorded in wetland categories and subcategories in the study area. X present, not recorded breeding; B present, recorded breeding; S present, but utilizing shallow areas (shores) only and ( ) very few records (irregular visitors, vagrants, unusual breeding habitat etc.).

Records of waterbirds in each of the following categories and subcategories:																
Species	1	2	3	4.1	4.2	4.3	4.4	4.5	5	6.1	6.2	6.3	6.4	7.1	7.2	
Great Crested Grebe								X	X	X				X	X	
Hoary-headed Grebe			B				B	X	X	X				X		
Little Grebe			B				B	X								
Australian Pelican								X	X	X				X	X	
Darter								(X)	(X)							
Black-faced Cormorant				B				X	X					(X)		
Pied Cormorant			X	B			X	X	X					X	X	
Little Pied Cormorant				(X)				X	X					X		
Black Cormorant			X	B			X	X	X	X				X	X	
Little Black Cormorant			X				X	X	X	X				X	X	
White-necked Heron	X	X	X				X	S								
White-faced Heron	X	X	X				X	S			X			S		
Cattle Egret	X		X	B			X	(S)		X	X					
Large Egret	X	X	X				X	S		X	X			S		
Little Egret			(X)					S								
Plumed Egret			X					S								
Nankeen Night-heron			X		(X)			S								
Little Bittern					X											
Brown Bittern					X			S								
Glossy Ibis	X		X					S								
White Ibis	X	X	X	B	B			S			X			S		
Straw-necked Ibis	X	X	X	B	B			S								
Royal Spoonbill			X	B				S		X	X			S		
Yellow-billed Spoonbill			X	B			X	S		X						
Plumed Tree-duck	(X)							(X)								
Black Swan	X		X	(B)	B		B	X	X	X	X			X	X	
Freckled Duck								(X)		(X)	(X)					
Mountain Duck	B	X	X					X	X	X	X	X		X		
Black Duck	X	B	B	B	B		X	X	X	X	X			X		
Mallard								(X)						(X)		
Grey Teal		X	B	B			X	X	X	X	X			X		
Chestnut Teal			B	B	X			X	X	X	X			X		
Shoveler			X					X	X	X	X			X		
Pink-eared Duck			X					X	X							
White-eyed Duck			X					X	X	X	X			X		
Wood Duck		X	X				X	X	X							
Blue-billed Duck	X							X	X	(X)						
Musk Duck							B	X	X					X		
White-breasted Saa-eagle				B				X	X	X				X	X	
Swamp Harrier	X		X		B		X	X	X	X	X			X		
Land Rail		X	X			B	X	X	X							
Water Rail		X	X	X												
Marsh Crake		X	X	X												
Spotted Crake		X	X		X											
Dusky Moorhen	X	X	X	X			B	X								
Swamphen	X	X	X				B	X								
Coot	X	X	X	X	B		B	X	X	X				X		
Painted Snipe		(X)	(X)													
Pied Oystercatcher														(S)		
Sooty Oystercatcher														(S)		
Masked Plover	B		B					S	S		X	X		S		
Banded Plover	B							S								
Grey Plover										(X)				(S)		
Eastern Golden Plover						B				(X)				(S)		
Red-kneed Dotterel								S			B			(S)		
Hooded Dotterel																
Double-banded Dotterel								(S)		X	X			S		
Red-capped Dotterel								S		B	X			S		
Black-fronted Dotterel			X					S	S							
Pied Stilt			X					S		X		B				
Banded Stilt								(S)		(X)						
Turnstone										(X)				S		
Eastern Curlew										(X)				S		
Whimbrel										(X)				(S)		
Grey-tailed Tattler														(S)		
Common Sandpiper														(S)		
Greenshank														S		
Japanese Snipe	X	X	X					S	X	X	X			S		
Bar-tailed Godwit								(S)		X	X			(S)		
Black-tailed Godwit														S		
Knot										X				(S)		
Great Knot										(X)				S		
Sharp-tailed Sandpiper			X					S	(S)	X	X			(S)		
Red-necked Stint								S	(S)	X	X			S		
Curlew Sandpiper										X	X			S		
Silver Gull	X		X					X	X	X	X			X		
Pacific Gull														X		
Whiskered Tern			X					X	X					X		
White-winged Black Tern								X	(X)					(S)		
Gull-billed Tern								(X)	(X)					(X)		
Caspian Tern								X	X	X				X	X	
Common Tern								X	X	X				X	X	
White-fronted Tern														(X)	(X)	
Little Tern								X	X	X				X	X	
Fairy Tern														(X)		
Crested Tern								X	X					X	X	
Common species																
Non-shorebirds	19	17	38	13	12	5	20	26	25	31	23	3	2	22	11	
Shorebirds								19	2					16		
Uncommon species																
Non-shorebirds	1	1	2	2	1			6	3	10	1			5	1	
Shorebirds								4	2					11		
Breeding species																
(included in above groups)	3	1	7	12	6	3	7			2						
Total Species	20	18	40	15	13	5	20	55	32	41	24	3	2	54	12	





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# HISTORICAL CHANGES ON SANDY SHORELINES IN VICTORIA

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**ABSTRACT:** Comparison of features mapped in the mid-19th century with those recorded on air photographs taken in 1935-45 and with the present configuration indicates the extent of recent changes on sandy shorelines in Victoria. In general sandy shorelines have receded, even on sectors where they had previously prograded (advanced seaward). During the past century, sandy shoreline progradation has been confined to a few scattered sectors where sand deposits are still arriving on the coast. These changes are likely to continue, and their possible effects should be considered by those concerned with the development and conservation of the Victorian coastline.

## INTRODUCTION

The changes that take place on coastlines as the result of erosional and depositional processes have long been of interest to geomorphologists, geologists and engineers. These changes can be studied over various time scales, ranging from a single tidal cycle or a weather episode lasting a few hours to such periods as the fortnightly spring tide cycle, or seasonal variations over a year; to variations over several years, or decades, or over the past century, or several centuries; and to changes that have taken place during the five or six thousand years since the Holocene marine transgression brought the sea up to approximately its present position.

In 1972 the International Geographical Union set up a Working Group to examine coastal changes around the world during the past century, using historical maps, charts and air photographs to trace changes in coastal configuration. By 1976, when the Group issued a preliminary report, it was clear that erosion had been widespread during this period, not only on cliffed coasts, but also on most of the world's sandy shorelines, including barrier sectors with a previous history of progradation (seaward advance) by means of Holocene sand accretion. The extent of the world shoreline that has prograded during the past century has been relatively limited (Bird 1976a). This world-wide study was based on the preparation of reports on national and provincial coastlines, including one from Victoria (Bird 1973a), which is here updated and extended as a record of the geomorphological changes

that have taken place on sandy shorelines on this part of the Australian coast.

## HISTORICAL EVIDENCE

In the mid-nineteenth century the Victorian coast was mapped on a series of Coastal Survey Plans, generally on a scale of two inches to the mile (Fig. 1), preserved in the archives of the Department of Crown Lands. In comparing these with the modern configuration, as shown on recent air photographs or portrayed on maps derived from these photographs and published on scales of 1:250,000 (National Mapping), 1:100,000, and in some areas 1:50,000 (Lands Department), possibilities of errors in surveying and cartography should be borne in mind (Carr 1962). It is not always clear whether the shoreline mapped was that of high or low tide or some intermediate level, or whether the coastline portrayed was the margin of vegetated terrain, such as grassy dunes at the back of a beach, or salt marsh or mangrove scrub behind muddy tidal flats. Where the coast consists of vertical cliffs the alignment is well defined, but where there is a bluff or an irregular coastal slope it is necessary to know whether the lines on the map represented the crest, the foot, or some intermediate feature. In view of these difficulties it is not usually possible to make precise measurements of coastal changes with reference to nineteenth century maps and charts, although much useful information can be gleaned, and some obvious changes detected. This has been illustrated with reference to Smythe's maps of the shoreline of Westernport Bay in 1849 (Bird

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& Barson 1975), and further examples will be given below.

The Victorian coastline was covered by air photographs taken by the Royal Australian Air Force between 1936 and 1945, the negatives being on scales ranging from 1:14,550 to 1:20,000. Earlier photography is available for parts of Port Phillip Bay, and some sectors have been photographed several times since the late nineteen-forties. Complete coverage is available from high-level photographs taken in 1965-7 (scale: 1:84,480) as a basis for the preparation of the National Mapping 1:250,000 series. Careful comparison of shorelines on photographs taken at different dates has been used to detect, and in some cases to measure, shoreline changes over the intervening periods.

Some possible sources of error must be acknowledged. Air photographs (especially the older ones) are subject to radial and tilt distortion, and the imagery may be further distorted by stretching or shrinkage of negatives or prints. The portrayal of the shoreline varies according to state of tide (on the Victorian ocean coast the inter-tidal zone is often 100 to 200 metres wide, and in embayments such as Westernport and Corner Inlet, much wider) and the state of the sea; it is sometimes difficult to trace a shoreline adjacent to shallow water areas where sea floor features are visible. Such features as bars (which may emerge at low tide), migratory berms, beach cusps, and beach lobes, complicate the recognition and delineation of a sandy shoreline. Changes in the extent of salt marsh and mangrove vegetation are usually obvious, but the extent of vertical change by erosion or sedimentation, relevant to the question of coastal advance or retreat, is usually too small to be demonstrable from air photographs, and transverse profiling by photogrammetric methods is impeded because the terrain surface is concealed by vegetation. On the other hand, changes on steep and cliffed coasts, often dramatic, are readily seen, and often measurable (Gill 1973, 1977).

The most effective method has been to enlarge or reduce the air photographs to a common scale (usually 1:10,000) for comparative study. On this scale it is not possible to measure changes of less than 0.2 millimetres, so that measurements are only accurate within  $\pm 1$  metre on the ground. Changes of this order can be detected on well-defined linear features such as vertical cliffs, eroding dune margins, or a truncated salt marsh, but changes on more gradual slopes or on open sandy beaches can rarely be determined within  $\pm 5$  metres. For more accurate data it is necessary to institute monitoring by repeated ground surveys along transverse shore profiles at selected locations. This has been done locally, on a limited scale, and for short periods, notably by the Ports and Harbors Division of

the Public Works Department in their investigations of eroding sectors where coast defence measures may be required.

In the absence of a comprehensive and sustained programme of monitoring past shoreline changes it is necessary to retrieve as much information as possible from cartographic evidence and air photography. On some sectors, dated ground or air oblique photographs, and even sketches or paintings, offer supplementary information on the configuration of the coast in the past. This kind of material has been sought from archives, but much of it is widely scattered and privately owned, and discovered only by chance. Possibly this attempt to put on record some evidence of recent changes along sandy sectors of the Victorian coast will bring to light further material relevant to the question of the nature and extent of such changes.

## THE VICTORIAN COASTLINE

The coastline of Victoria (including Port Phillip and Westernport Bays) is about 1700 km long, when measured by means of one-kilometre intercepts on 1:250,000 maps. Of this, about 700 km are sandy shoreline, backed by sandy terrain such as beach ridges or coastal dunes. The remainder is partly steep and rocky, in the form of cliffs and bluffs, some of which are bordered by narrow beaches of sand or gravel, and partly low-lying alluvial and swamp terrain, with a seaward fringe of salt marshes, and in some places mangroves. Further details are available in a geological and geomorphological account of the coast of Victoria published by the Town and Country Planning Board (Bird 1977). Evidence for recent changes on this coastline will be treated in sequence from Discovery Bay in the west to Cape Howe in the east.

## DISCOVERY BAY

The long, gently curving sandy shore of Discovery Bay is backed by extensive dune topography, including large active dunes. The seaward margin is generally cliffed, partly in dune calcarenite (as at Cape Montesquieu), and partly in unconsolidated, grassy foredunes. Although at times constructive wave action builds up the beach, and wind action develops a newer foredune or grassy terrace,\* these features are not maintained, and comparison with historical maps and air photographs indicates that the sandy shoreline has retreated. Near the western end, the beach is interrupted by the mouth of the Glenelg River, the features of which were surveyed by Thomas Mitchell in 1836.

\*Foredune ridges are built upwards by sand accretion in tussocky grasses (*Festuca littoralis* or *Ammophila arenaria*), whereas terraces are built outwards by sand accretion in spreading grasses (*Spinifex hirsutus*).



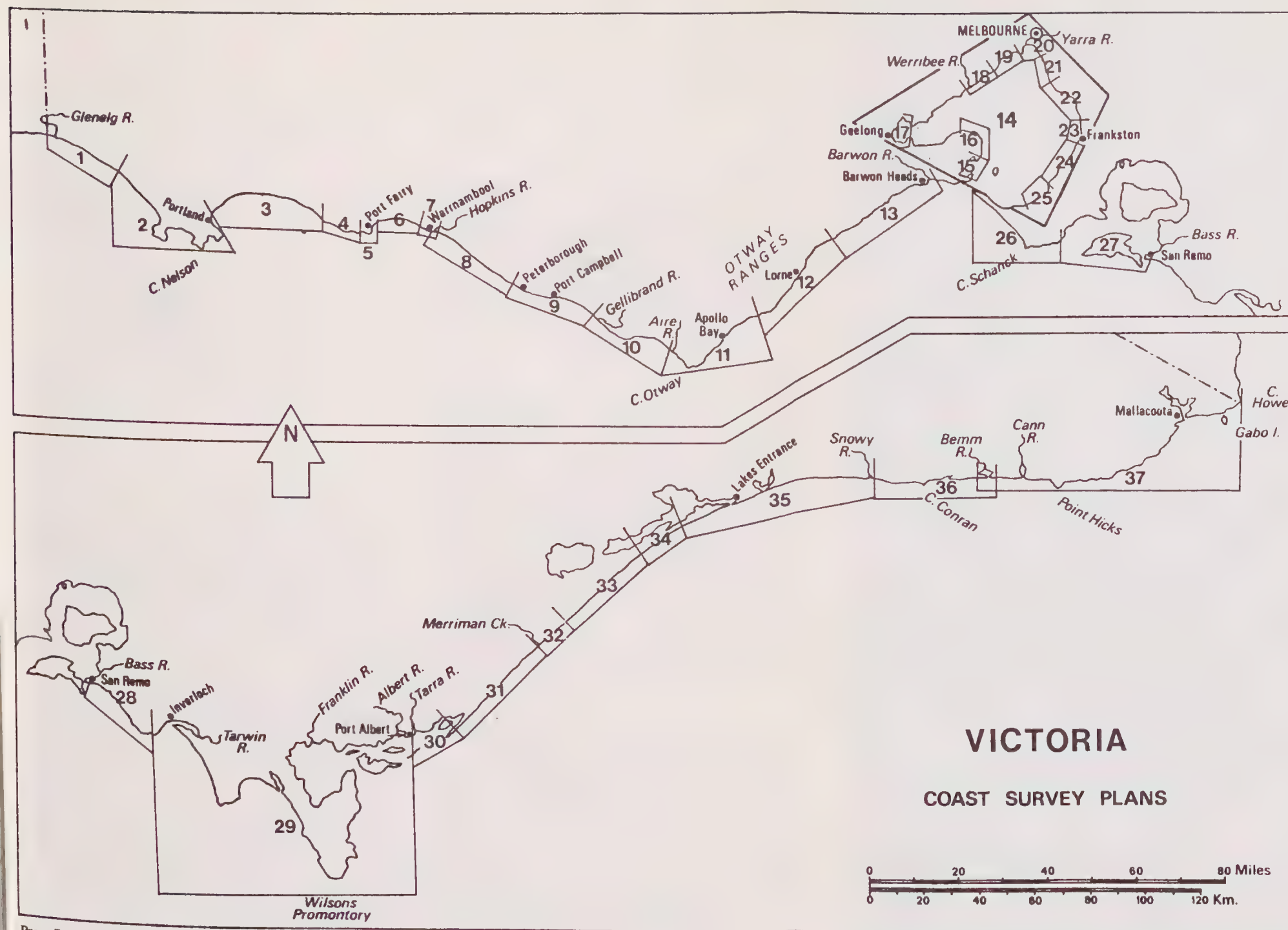


Fig. 1—

1. Clarke 1850
2. Clarke 1850
3. Wade 1851
4. Townsend 1840
5. Barrow 1850
6. Barrow 1854
7. Barrow 1853
8. Smythe 1847
9. Smythe 1847
10. Smythe 1847
11. Smythe 1869
12. Smythe 1846
13. Smythe 1847
14. Hobson 1836
15. Ross 1860
16. Cox 1861
17. Ross 1859
18. Cox 1861
19. Cox 1861
20. Ross 1858
21. Cox 1861
22. Cox 1862
23. Cox 1862
24. Cox 1862
25. Cox 1862
26. Smythe 1841
27. Smythe 1842
28. Smythe 1843
29. Smythe 1847-48
30. Smythe 1847
31. Smythe 1847
32. Smythe 1847
33. Smythe 1848
34. Smythe 1848
35. Smythe 1849
36. Smythe 1849-52
37. Smythe 1849-52





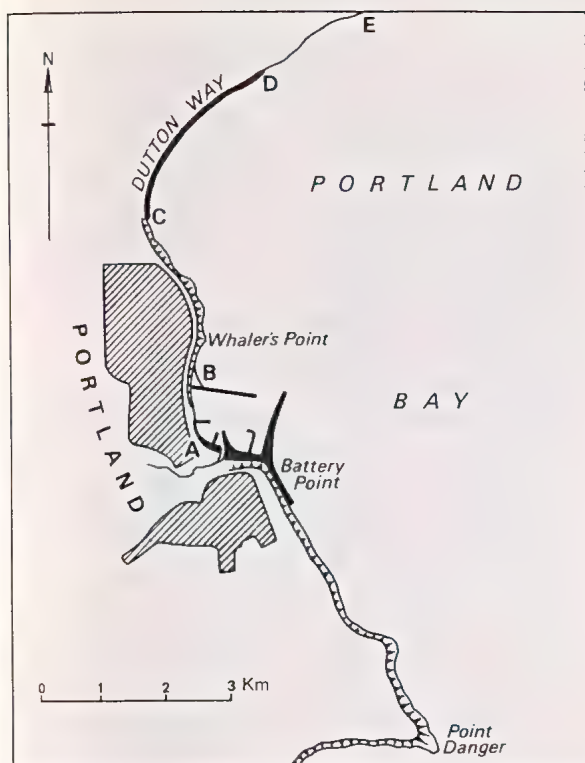


Fig. 2—Coastal features near Portland, Victoria.

Comparison of Mitchell's map with an air photograph taken in 1967 shows little change, except that there is now a more winding outlet from the river through a more extensive sandy threshold at the mouth, and the dunes immediately to the east have been cut back, and only partly rebuilt (J. F. Bird 1977).

#### BRIDGEWATER BAY AND THE PORTLAND COAST

Bridgewater Bay, between steep promontories of hard volcanic rock west of Cape Nelson, also has coastal dunes with a seaward margin trimmed back by marine erosion, and the same is true in Portland Bay, except for a small sector near the town of Portland, where the sandy shoreline has advanced within the harbour area (A, Fig 2). Comparison of Tyers' plan of Portland Bay, surveyed in 1840, with later maps and air photographs shows that the beach prograded after piers were built in 1846 and 1857-8, and particularly after the construction of a breakwater in 1891. Later these structures were removed or modified, and the present large stone breakwaters added in 1957-61 to enclose Portland Harbour. The prograded beach has been partly built over, but further accretion has taken place on the northern side of the lee breakwater (B, Fig 2), and it appears that breakwater construction has modified the pattern of waves in such a way as to create a sheltered environment into which beach sand has drifted.

There has been rapid beach erosions at Dutton Way, to the north, during the fifteen years since the large breakwaters were built at Portland, and it is possible that these breakwaters now refract the waves in such a way as to intensify wave energy reaching this shore. Boulders have been dumped to reduce erosion (CD, Fig 2), but as on other parts of the coast this has been followed by a narrowing and lowering of the beach in front of the boulders, while erosion has continued (and perhaps intensified) beyond their eastern limits (DE, Fig 2), where the eroding sandy shoreline is backed by multiple dune ridges indicative of earlier progradation. Dutton Way is thus a sector where erosion has accelerated as a sequel to engineering works, but sandy shoreline erosion is so widespread that there would probably have been some erosion here even without such structural modifications.

#### PORT FAIRY

Local progradation has taken place alongside breakwaters built in the eighteen-seventies to secure a navigable entrance to the river-mouth harbour at Port Fairy. Barrow's plan, surveyed in 1854, and Stanley's chart of 1870 show several rocky islands off the mouth of the Moyne River, with extensive intertidal and submerged sand shoals. Later maps and air photographs show that since the breakwaters were built and extended, sand has accreted above high tide level to advance the shoreline on their southern side, along the broad beach linking Griffith Island to Rabbit Island. On the northern side the beach has been cut back, and shore protection works have been introduced, with similar effects to those at Dutton Way, but there has been little change in the sandy shoreline behind the basalt reefs at Killarney.

#### WARRNAMBOOL

Cliffs in Pleistocene dune calcarenite south and west of Warrnambool have been subject to erosion during storms, but Lady Bay has been a sector of beach progradation. Early maps show that the Merri River opened to the sea alongside a sand spit at the western end of Lady Bay, in the lee of a chain of rocky islands and reefs. Attempts were made to improve the shelter of this part of Lady Bay as a boat anchorage, notably by the building of a viaduct to link one of the offshore islands to the mainland, and a stone breakwater extending out from this island into Lady Bay. As these structures were built (1884-90) the sandy shoreline to the north began to prograde, and in 1925 the Royal Commission on Victorian Outer Ports estimated that during the preceding forty years some 1.2 million cubic yards of sand had been deposited, advancing the beach within the harbour by about 150 yards. The viaduct

was then filled in to form a causeway, with the aim of preventing inflow of sand from the mouth of the Merri River (then assumed to be the major source of the sand), and the breakwater was extended out into deeper water. However, progradation has continued with sand being washed up from the floor of Lady Bay, and harbour remains very shallow (Duberry 1978).

#### APOLLO BAY

Apollo Bay is another sector where local beach progradation has occurred within a harbour as a sequel to breakwater construction. Again the harbour lies on the lee side of a headland, and is sheltered from ocean swell and waves generated by the prevailing south-westerly winds. Engineers have sought to improve the natural anchorage by building protective breakwaters, and in so doing have created an environment where sand deposition has ensued in one area when beach erosion has prevailed elsewhere. Comparison of air photographs taken in 1946 and 1974 shows that deposition has occurred mainly to the north of the harbour, where grassy dunes have formed behind a sandy beach that has built up within the past thirty years (Plates 3 & 4 in Bird 1973a).

#### PORT PHILLIP BAY

Recession has taken place along cliffs and intervening beach sectors on the ocean coast between Cape Otway and Wilsons Promontory, but patterns of change have been more complex within Port Phillip and Westernport Bays. At the entrance to Port Phillip Bay, Point Lonsdale Bight receives an intermittent supply of sand drifting in from the ocean shore, particularly during winter storms, when sand drifting from the west moves round the point and northwards past Point Lonsdale (McArthur 1977). The sector north to Queenscliff and Swan Island has been built up in Holocene times by the deposition of sand swept into the entrance to Port Phillip Bay and carried northward by a combination of south-easterly waves and current action (Fig 3). Swan Island is essentially a recurved spit, which has shown complex changes in configuration. Riedel and Fidge (1977) examined fifteen surveys carried out between 1886 and 1976, and found evidence of the migration of successive lobate forelands along the eastern flank of Swan Island, one reaching the northern end between 1910 and 1923, the next between 1949 and 1968.

Nautical charts of 1837 and 1859-60, and the military map of 1928, show a variable barrier and spit

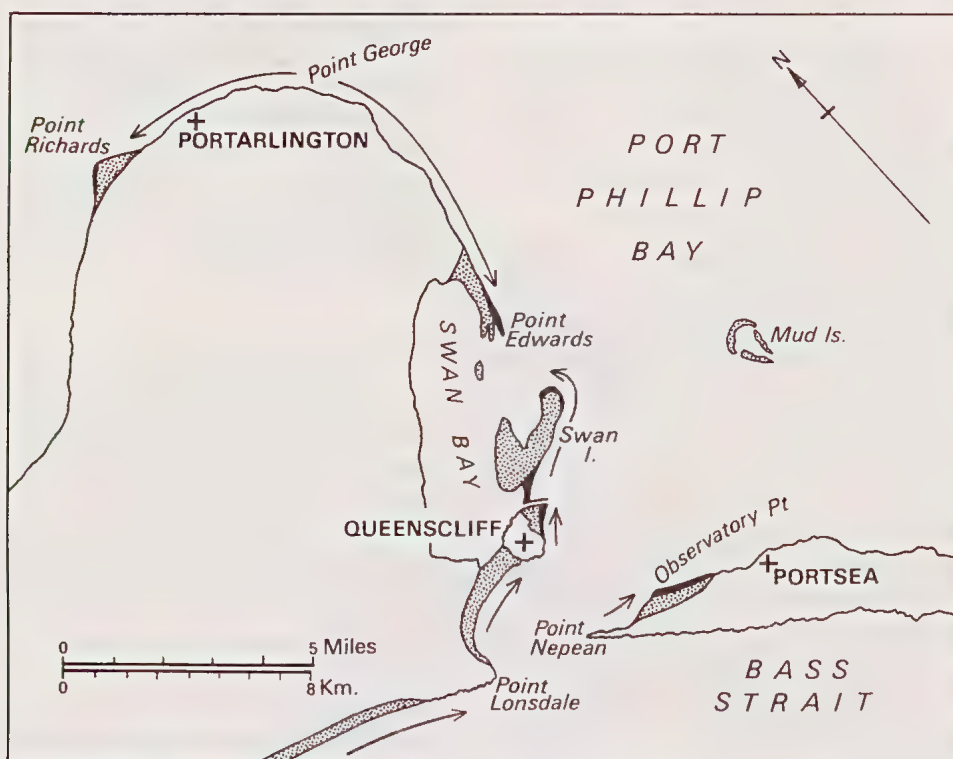


Fig. 3—Coastal features and longshore drifting at the entrance to Port Phillip Bay. Sandy areas are stippled, except for sectors of historical progradation, shown in black.



topography in the area between Queenscliff and Swan Island, and fluctuations of the tidal channel here may have been responsible for the irregularities in sand supply to Swan Island, producing the migrating lobate forelands. A breakwater was built at Queenscliff in 1935 and extended in 1955-6 to protect the entrance to a boat harbour. After the breakwater was extended there was rapid sand accretion on its southern side between 1957 and 1961, when about 1.25 million cubic metres accumulated in the form of a triangular foreland (Riedel & Fidge 1977). North of the breakwater the barrier and spit topography has been reshaped, and with the sand supply interrupted, erosion has become prevalent on the eastern shore of Swan Island (Plate 1). By 1961, accretion had prograded the shoreline south of the breakwater to such an extent that sand was moving into the approach to the boat harbour. Repeated dredging is necessary to maintain the channel by removing about 70,000 cubic metres of sand per year and dumping it in the shoal area to the north.

Changes have also occurred on the shores of Lonsdale Bight, which are backed by dunes built up during an earlier phase of deposition, but are now cliffed and eroding. The drift of sand along and across Lonsdale Bight has been insufficient to maintain the

shoreline here. Erosion of the shoreline became severe at Point Lonsdale in the early years of the present century, after the navigable entrance channel to Port Phillip Bay had been enlarged by blasting away part of the rocky sea floor (Dunn 1970.) It is unlikely that this change in sea floor configuration had much effect on wave and current patterns; it is more likely that here, as elsewhere on the Victorian coast, beach erosion had already begun, and that it was noticed only after the township of Point Lonsdale had been sited there. The response to this erosion has been the building of sea walls and groynes in a sequence that has gradually spread along the shores of the Bight, with continuing, and perhaps accentuated, erosion cutting out asymmetrical coves beyond each extension in turn (Fig 4). Despite criticisms of this kind of sea wall construction, it seems inevitable that the whole of Lonsdale Bight will eventually be walled, and that local people will either have to be content with the lower and narrower sandy beaches that survive in front of walls of this kind, or ask for the beach to be restored artificially (McArthur 1977).

Edwards Point, north of Swan Island, is a similar spit that has grown southwards, the two structures comprising a paired spit formation that constricts the



PLATE 1

The eastern shore of Swan Island, Port Phillip Bay, showing a migrating sand lobe. (*N. Rosengren, August 1973*)

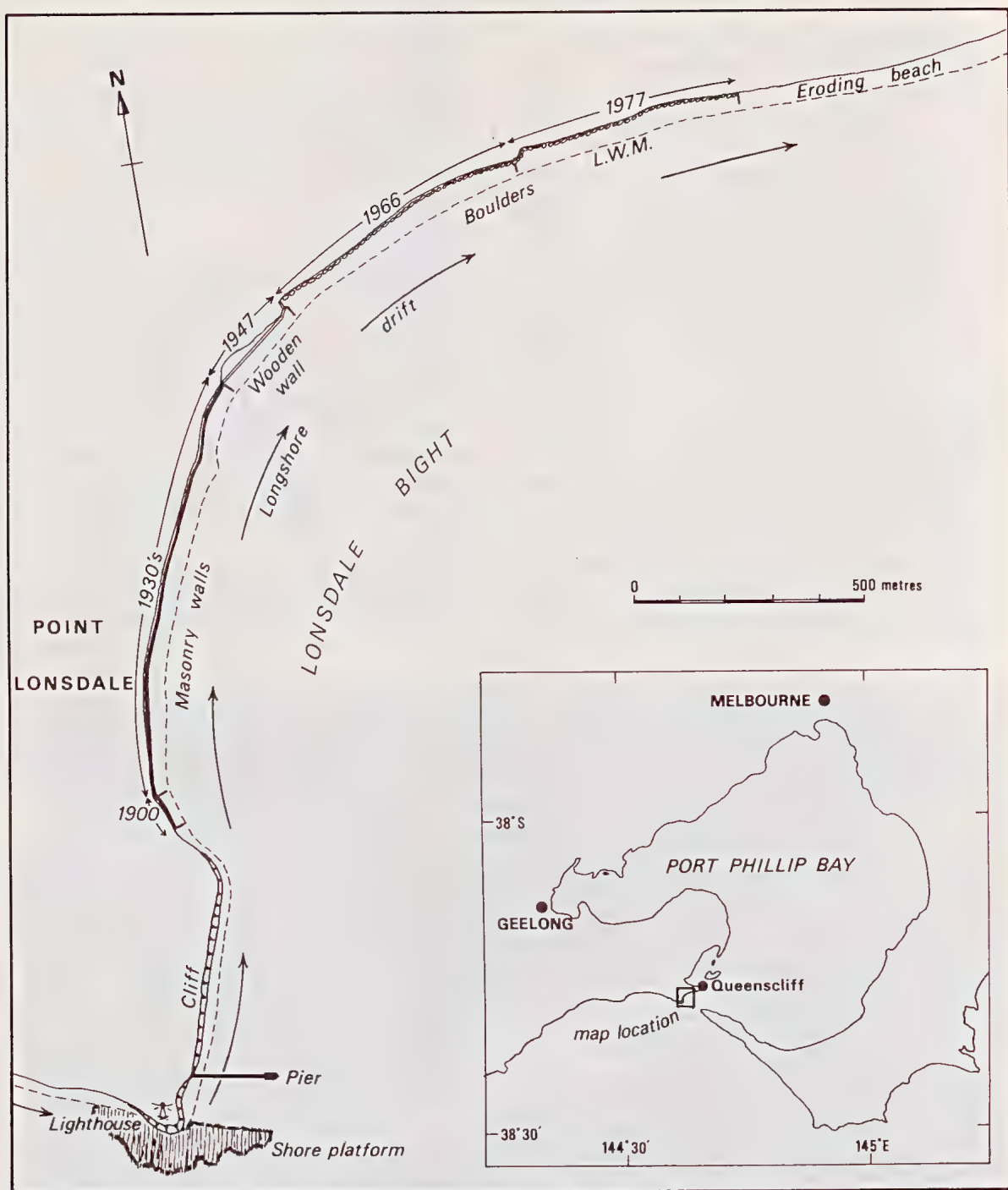


Fig. 4—Sequence of sea wall construction in Lonsdale Bight.

entrance to Swan Bay (Fig 3). The present outer sand ridge, not shown on 19th century maps and charts, has been added since Mason's survey of 1896. The spit incorporates quartzose sand and some ferruginous gravel which has drifted southwards from the eroding cliffed coast at St. Leonards, together with shelly gravel derived from the fauna of adjacent shallow

waters (Barson 1973). At St. Leonards there has been local cusped deposition within a small harbour, and minor accretion on the sandy foreland to the north.

Point Richards, west of Portarlington, is a cusped foreland that has gained new ridges on its western shoreline in recent decades (Fig 3). It is similar to Edwards Point in composition, and is supplied by



westward drifting of sand and gravel. A 'drift parting' thus exists near Point George, as the result of the arrival of waves generated by winds from the quadrant between NNE and ESE, where the fetch across Port Phillip Bay attains 40 km. On the western shore of Port Phillip Bay the shelly spits and islets at the Sand Hummocks have shown intricate, small scale changes in outline on air photographs taken in 1947, 1970, and 1974, the overall trend being one of shoreline recession. At Altona and Williamstown, changes have been due largely to reclamation works and sea wall construction, and in recent years beaches have been artificially replenished.

There are several minor sectors of sustained sand accretion related to the building of breakwaters to shelter boat harbours on the eastern shores of Port Phillip Bay, notably at St. Kilda and Brighton, where cusped forelands have developed in the lee of breakwaters; Sandringham, where the harbour breakwater has intercepted beach material that formerly moved to and fro in a seasonal drift alternation (Bird 1972); Mordialloc, where sand accretion has occurred on the northern side of a breakwater; and Rye, where progradation has been augmented by the dumping onshore of sand dredged from offshore sources. Cluffed sectors of this shoreline have generally receded, although sea wall construction has halted this, especially since the nineteen-thirties. Many of the former cliffs have been replaced by landscaped bluffs, as at Brighton, Black Rock, and Mentone, a procedure that has cut off the former supply of sand from the cliffs and resulted in beach depletion (Bird 1972). Natural erosion, hastened by the impact of people scrambling on the cliffs, is still to be seen at Red Bluff and Black Rock Point (Bird, Cullen & Rosengren 1973). In recent years the P.W.D. Ports and Harbors Division has initiated artificial beach nourishment schemes, using sand dredged from the sea floor, to replace eroded beaches at Mentone and Aspendale, and this method is likely to be used elsewhere to restore or improve beaches in demand for recreational use.

Observatory Point, south of Portsea, is a sandy foreland that developed in stages marked by beach ridges on a sector where ocean swell, refracted through Port Phillip Heads, has combined with locally-generated waves and currents to supply and shape an area of sand deposition (Fig 3). The western shore is now cluffed and receding, a change that could be attributed to intensified wave energy following the enlargement of the entrance to Port Phillip Bay, but is probably part of the more widespread onset of sandy shoreline erosion here documented. Some of the sand eroded from this shore has drifted round to the north-facing shore, which has continued to advance, and thus shows the features typical of a prograding sandy

shoreline. The transverse profile of the beach is convex-upward, backed by a newly-developed beach ridge which is being colonised by dune grasses; the resulting foredune remains uncluffed, and uninterrupted by blowouts.

Mud Islands, a group of low sandy and marshy islets on a shoal in the southern part of Port Phillip Bay, have varied in configuration since they were first mapped in 1836. The changes have been traced from maps and charts compiled in 1859-60, 1864, 1932 and 1946, and from air photographs taken in 1951 and 1969 (Bird 1973b). In the course of these changes a new ridge of shelly sand was added to form Boatswains Beach on the southwestern shoreline, but this progradation was only temporary, for in 1962 a storm surge drove the beach back on to the salt marsh to the rear, so that the present shoreline is in much the same position as that of 1836.

#### WESTERNPORT BAY

Recent changes on shorelines bordering Westernport Bay were described and discussed by Bird and Barson (1975). There has been further erosion on sandy sectors, notably at Somers and Cowes, and accretion on spits supplied with sand by longshore drifting: accretion during the past four years has widened Sandy Point, added a new recurve to Stockyard Point, and lengthened Observation Point on Phillip Island. There have also been gains and losses in the extent of salt marsh and mangroves on the shores of Westernport Bay, with continuing revival of mangroves in some sectors from which they had previously disappeared, notably to the south of Stony Point.

At the eastern entrance to Westernport Bay, sand is being supplied to the shores of Cleeland Bight by an active dune spilling from the isthmus north of Cape Woolamai. A combination of south-easterly wave action and inflowing tidal currents has carried this sand around the shores of the Bight, which have prograded by up to 300 m since this area was surveyed by Smythe in 1842 (Plate 2). Recently-built foredunes back sectors of this shoreline north to the road bridge, and there has been similar accretion on Davis Point, south of San Remo, where foredune growth proceeded in the interval between 1939 and 1973 air photography. The sand supply here is derived from shoals to the south, which are probably fed, in turn, by tidal redistribution of sand arriving in Cleeland Bight.

#### SOUTH GIPPSLAND

Cliffs and beaches on the ocean coast between San Remo and the western shores of Wilsons Promontory have generally receded, but in two sectors there has been an advance of the sandy shoreline in recent





PLATE 2

The prograded sandy shoreline in Cleeland Bight, on the east coast of Phillip Island, fed with sand from the active Woolamai dunes in the background. (E. C. F. Bird, February 1977)



PLATE 3

Sand shoals moving into the entrance to Andersons Inlet at Inverloch. A spit is building up off Point Smythe, to the left, and lobes of sand are migrating along the Inverloch shore, to the right. (*K. G. Boston, March 1976*)

years. South of Inverloch new grassy beach ridges have added to the western shore of Venus Bay, and an extensive sandy flat has built up off Point Smythe, narrowing the tidal channel at the mouth of Andersons Inlet (Plate 3). A lobe of sand has moved in along the Inverloch shore since 1950 (Boston 1971) in much the

same way as have the sand lobes on Swan Island. Prograded sandy terrain has also developed on sectors of the shoreline of Waratah Bay on either side of the migratory mouth of Shallow Inlet (Smith 1969). Within Andersons Inlet, Boston has documented early stages in the development of new marshland and the



associated re-shaping of intertidal topography following the introduction of *Spartina anglica* in 1962, a remarkable example of a vegetation-induced coastal change (Boston 1973).

#### WILSONS PROMONTORY AND CORNER INLET

Changes have been very slow on the hard granites of Wilsons Promontory: indeed, the period since the Holocene marine transgression brought the sea to its present level has seen little change here beyond the removal of the weathered mantle and the development of minor weathering features on the bedrock surfaces thus exposed. The southern shores of Corner Inlet have been receiving sand from active dunes spilling from Yanakie isthmus in much the same way as those of Cleeland Bight, but this area is sheltered from strong wave action and the sand has been dispersed, largely by tidal currents, to form intertidal shoals instead of prograding the beach. Salt marsh and mangrove-

fringed areas on the northern and western shores of Corner Inlet have shown changes similar to those described by Bird and Barson (1975) at Westernport Bay, but these have not yet been investigated in detail.

Sandy shorelines in each of the coves bordering Wilsons Promontory have receded during recent decades to produce cliffed dune margins, but on the northeastern corner there is an extensive beach ridge system, and a part of the coastline here has advanced as a new sandy foreland, while adjacent shores to the north and south have been cut back. A comparable bulging of the shoreline occurred at earlier stages, commemorated in the pattern of beach ridges farther inland (Plate 4). Such irregularities in growth probably result from changing patterns of refracted waves over the variable shoals off the adjacent entrance to Corner Inlet.

Similar changes have occurred on the shorelines of barrier islands east of Corner Inlet. The



PLATE 4

Air photograph of northeast Wilsons Promontory. (Crown copyright reserved: Department of Minerals and Energy, Canberra, February 1965)



southern shores of Snake Island have been cut back, but at the Port Albert entrance there has been extensive sandy shoreline progradation. Comparison of air photographs taken in 1941 and 1967 shows the addition of a large sandy area, built up above mid-tide level on the western side of the entrance (Plates 13 & 14 in Bird 1973a). The sandy shoreline east of the entrance has retreated, but there has been substantial accretion at the entrance to Shoal Inlet, 16 km to the east, where a spit grew southwestwards by more than a kilometre in the interval between 1941 and 1967.

#### THE NINETY MILE BEACH

The long sandy shoreline of the East Gippsland coast typically shows a cliffed dune margin to the rear of the present beach (Plate 5), and comparisons of the Coastal Survey Plans (1846-49) with air photographs taken in 1967 indicate that a recession of up to 150 metres has taken place. The Ninety Mile Beach is the seaward margin of an outer barrier that had previously prograded to form a succession of dune ridges. Such dunes develop as the result of alternations of shoreline advance and retreat (sequences of 'cut-and-fill' as described by Davies in 1957), and one interpretation of the present situation could be that a retreat phase has lately prevailed, and will duly give place to another advance phase, when a new and persistent sand ridge will be added to prograde the shoreline. However, the present retreat phase has been on a much larger scale

than any earlier phase of shoreline recession, for the previously-built dune ridges show no evidence of earlier episodes of disruptions by blowouts comparable with those that have now developed from the seaward margin. There have been recurrent phases of new foredune initiation in front of sectors of cliffed dune margin, but these are impersistent, and do not survive episodes of storm wave activity. For some reason the intermittent shoreline progradation that prevailed earlier in Holocene times has given place to a dominance of erosion.

The dune ridges were built roughly parallel to the Ninety Mile Beach, but vary in number from one at Seaspray, Bunga Arm and Lakes Entrance to thirteen at Letts Beach. Where there is only one, it has generally been a transgressive ridge, moving landward as the beach was cut back, and now held in place by marram grass plantings; where there are several, the lateral variation is due partly to divergence, and partly to truncation of sinuous ridges along the present backshore (Huzzey 1975). In the McLaughlins Beach sector up to six ridges have been pared away along a straightened shoreline that truncates an earlier lobate foreland.

As the beach was cut back, blowouts formed, and in many places sand is spilling across the previously vegetated dune ridges behind the Ninety Mile Beach. At McLaughlins Beach a meandering tidal channel behind the outer barrier broke through in a



PLATE 5

A receding sandy shoreline: the Ninety Mile Beach near Ocean Grange. (*E. C. F. Bird, November 1965*)

storm in 1961 to form a new outlet that has since widened. At Seaspray, there have been changes at the mouth of Merrimans Creek since it was mapped in 1847 by Smythe. These are due partly to shoreline retreat and the landward movement of dunes (McKay 1978).

The only part of the Ninety Mile Beach that has advanced is a 2.5 km sector extending either side of the stone jetties that protrude from the artificial entrance to the Gippsland Lakes (Bird & Lennon 1973). Sandy forelands have prograded here, linked by a submerged, looped sand bar off the entrance; their growth is indicated by successively-built foredunes, particularly on the southwestern side. The sand has been supplied by longshore drifting, its interception being related to the breakwaters, and to the effects of constructive wave action on either side of the zone where transverse currents flow in and out of the Gippsland Lakes (Bird 1965, 1978). The pattern of accretion is unusual. As a rule, such breakwaters intercept longshore drift to prograde the up-drift shoreline and result in erosion down-drift, but here there has been accretion on both sides, with longshore drifting from the northeast as well as from the southwest. According to Fryer (1973) the volume of sand accretion in the prograded forelands and looped bar structure is about 13 million cubic metres. Undoubtedly, much of this local accretion has been due to accumulation of sand eroded from the Ninety Mile Beach, which has also been losing sand landward, through blowouts to spilling dunes behind the shore, and seawards to the intermittent sand bars observed in the surf zone.

#### LAKES ENTRANCE TO CAPE HOWE

East of Lakes Entrance, little change can be detected on the sandstone headland at Red Bluff, or on the granitic promontories and cliffs of Lower Palaeozoic rock farther east, but shoreline recession has prevailed on the long sandy beaches that line much of this coast. Minor sectors of at least temporary progradation have been noted at Point Ricardo and Wangan Inlet (Plate 8, Rosengren 1978), and at Pearl Point (Williams 1973) and Clinton Rocks (Harford 1973). At Mallacoota, comparisons of air photographs taken in 1941 and 1966 show removal of a sand ridge on the eastern shore and accumulation of sand on the threshold area that extends into the mouth of the Inlet (Plates 15 & 16 in Bird 1973a). The entrance to Mallacoota Inlet has become very shallow, and occasionally it has been sealed off completely (Williams 1977). Farther east, the cusped feature on the coast behind Gabo Island is the remains of a tombolo that existed here in the 19th century (Rosengren 1978); it changed little in outline between 1941 and 1966, apart from

some paring away of the eastern shoreline, but there have been variations in the topography of largely unvegetated and mobile dunes that extend eastwards through the coastal fringe towards Cape Howe.

#### DISCUSSION

There has been a prevalence of erosion on sandy sectors of the Victorian coastline during the past century. Beach progradation has been confined to a few limited and localised sectors still receiving a sand supply from nearby cliff erosion, from offshore shoals, or from dunes spilling on to leeward shorelines; to the growing spits and cusped forelands nourished by a sand supply derived from nearby erosion; and where longshore drift has been intercepted by breakwaters built to protect harbour entrances. Elsewhere, the beach systems have been losing sand, partly onshore to dune systems, partly alongshore and into the mouths of estuaries and lagoons, and partly offshore to the sea floor. This is a world-wide problem, and several hypotheses have been put forward to explain it, each of which will now be considered in a Victorian context.

On many coastlines, beaches are supplied and maintained by sediment delivered to the coast by rivers and transported by longshore drifting. Where this is the case, as in Southern California, the onset of beach erosion has been correlated with the reduction of fluvial sediment yield following dam construction and reservoir impoundment (Emery 1960). However, this is of little relevance in Victoria, where most of the rivers flow into estuaries or coastal lagoons, which receive the bulk of the sediment discharged. An exception is the Snowy, which carries sand and gravel into the sea at Marlo during occasional episodes of flooding. Thus in February 1971, when severe floods scoured sand and gravel from the river channel, it was noted that this petrologically and granulometrically distinctive sediment was afterwards present on the beach near the river mouth (McLennan 1972). It was soon dispersed by shore processes, and evidently this occasional delivery of fluvial sand has not been sufficient to maintain or prograde the shoreline at the mouth of the Snowy.

On some sectors of the coast, beaches are supplied with sediment eroded from nearby cliffs and rocky shore outcrops. Gill (1978) has demonstrated a relationship between the volume of sand thought to have been generated by Holocene recession of dune calcarenite cliffs east of Yambuk and the volume of sand deposited in Holocene times on Cape Reaumur, a promontory that has trapped sand drifting eastwards. The onset of beach erosion here would presumably be the outcome of a diminishing rate of sediment yield from the eroding cliffs. However, in essaying such





PLATE 6

The prograded grassy sand terrace in the bay at Wingan Inlet, shortly before it was cut away by storm waves. (*N. Rosengren, November 1973*)



correlations it is necessary to take account of losses by solution and attrition, as well as inputs from more distant alongshore and from offshore sources, and the validity of correlation depends on a strict lithological equivalence of the eroded and deposited sand. Along the Otway and South Gippsland coasts, for example, the beaches are of calcareous and quartzose sand while the formations eroding in the cliffs are felspathic; and in East Gippsland the quartzose Holocene beach deposits that extend from Corner Inlet to Cape Howe cannot be correlated with sediment yields from the very limited cliffy sectors. The bulk of the sand forming beaches and coastal dunes in Victoria has evidently been supplied from the sea floor during successive marine transgressions in Quaternary times (Bird 1961), and the onset of erosion should be sought in terms of a diminution in this source of supply.

An explanation may be found in changes in the relative levels of land and sea. Fairbridge (1966) reported evidence from tide gauge records of a worldwide rise of sea level during the past century, at an average rate of just over a millimetre a year. According to Bruun (1962) a shoreline that had previously attained a transverse equilibrium profile would recede in response to such a sea level rise, sand being transferred from the beach to the nearshore sea floor in such way as to restore the transverse profile farther landward (Fig 30 in Bird 1976b). This sequence has been observed on the shores of the Great Lakes in North America during phases of rising lake level, such as the one-metre rise recorded in Lake Erie between 1965 and 1974 (Carter 1976). However it is unlikely that the much smaller rise of sea level, averaging only about a millimetre a year, has had much effect on an ocean shore, where heavy swells and storm waves sometimes exceed 3 metres in amplitude.

It is difficult to determine whether the sea level rise reported by Fairbridge has actually taken place on the coast of Victoria. Indeed, the only long-term tide gauge records available in southeastern Australia are those for Williamstown, at the head of Port Phillip Bay (1858-1939 and 1943 onwards), and Fort Denison, in Sydney Harbour (1867 onwards) (Easton 1970). According to Mackenzie (1939) the levels of mean high and mean low spring tides recorded on the Williamstown tide gauge over three periods 1874-88, 1888-1916 and 1916-35 varied by only  $\pm 0.01$  feet, indicating no significant change in mean sea level within Port Phillip Bay between the eighteen-seventies and the nineteen-thirties, but the validity of long-term sea level deductions from this gauge has been questioned by Bradley (1949). On the other hand, the Fort Denison tide gauge has shown irregular fluctuations of annual sea level over the period 1890-1962, reaching a peak of 3.22 feet in 1919 and troughs of 2.80 feet in

1916 and 1927. The 1962 mean was 3.10 feet, compared with 3.16 in 1890 (Foster 1970). Thus neither station supports the concept of a rise of sea level during the past century, but the Williamstown record could include a response to the blasting of a deeper entrance channel to Port Phillip Bay after 1900, and the Fort Denison record may have been influenced by dredging and reclamation within Sydney Harbour. Unfortunately, there are no stations on the ocean shore that have been in operation long enough to determine sea level trends in the coastal environment.

The effects of tectonic subsidence in coastal regions would be similar to those of a sea level rise, but there is no evidence of such subsidence along the Victorian coast during the past century.

It has been argued that an increase in storminess in coastal waters could lead to the onset of erosion on sandy shores that had been built up under earlier, calmer conditions. Climatic records are too brief to permit a comparison of the incidence and severity of storms during the past century with conditions at earlier times, and so this hypothesis cannot be tested. However, Wilson and Hendy (1971) have argued that an increase in storminess is likely to be correlated with cooling phases of climatic history, when the thermal gradient between the equator and the poles steepens. As such phases are also correlated with falling, rather than rising, sea levels, it appears that the past century should have been an era of diminishing, rather than increasing, storminess.

Even within Victoria, sandy shoreline erosion has been too widespread to be attributable, directly or indirectly, to man's interference, although there have certainly been localised effects following the construction of sea walls and breakwaters. Reduction of backshore dunes following the depletion or removal of vegetation by trampling, burning, and stock grazing has been documented on the Victorian coast (e.g. Rawlinson 1877), and this could have accelerated coastal retreat by diminishing the volume of terrain to be removed as the shoreline is cut back, but it cannot explain *initiation* of sandy shoreline erosion.

Finally, it has been suggested by Tanner and Stapor (1972) that the onset of sandy shoreline erosion, as a sequel to earlier progradation, is an inevitable consequence of an episode of sea level stillstand following the Holocene marine transgression. It is now widely acknowledged that this sea level rise was accompanied by the collection and shoreward drifting of sediments, including sand deposited by rivers draining to lower late Pleistocene sea levels, relics of beach, barrier and dune sands left stranded during the preceding sea level fall, and sandy weathered materials that mantled the submerging land surface (e.g. La Bourdieu 1958, Bird 1961, Russell 1967, Thom 1968, 1974). It



is possible that the accumulation of sand was stimulated by episodes of stillstand and regression during an oscillating Holocene marine transgression, and that when sea level became relatively stable, sand accumulated at the coast until a transverse 'profile of equilibrium' had been attained with respect to the present stillstand. Thereafter, with continued input of wave energy, any sectors of coast not still receiving fluvially-supplied or cliff-derived sand began to migrate landward to compensate losses from the shore system, whether by wind action to hinterland dunes, longshore drifting into estuarine or lagoonal 'traps', or withdrawal into deep water offshore. The volume of beach material is also reduced by gradual attrition of wave-agitated sand grains.

The onset of this erosion will have taken place at different times in different places, varying with the quantities of relict sea floor sand available within the 'offshore catchment' of each beach sector, the rate at which shoreward drifting had taken place, and the extent of natural replenishment (if any) from rivers, cliffs, or eroding beaches alongshore, or contemporary biogenic production of shelly sands (Gell 1978).

The sequence of events on sandy sectors of Victorian sandy coastline fits this hypothesis well. On the East Gippsland coast, sand was carried shoreward during the Holocene marine transgression, and for some time after the present stillstand was established, and deposited to form the outer barrier seaward of the Gippsland Lakes, a barrier that prograded with the addition of successive dune ridges (Bird 1961). Off Corner Inlet there are still shoals, from which sand is moving onshore to prograde the coast near Port Albert. Along the Ninety Mile Beach this supply is no longer available: the transverse profile extending offshore is smooth, and gently concave-upward. In the absence of a fluvial sand supply, or sand-yielding cliffy sectors, losses of sand from the beach can no longer be replenished from the sea floor; instead, wave action is withdrawing sand to the sea floor as the transverse 'profile of equilibrium' migrates landwards, gradually consuming the outer barrier. The date of the onset has not yet been determined; a stratigraphic dating programme of the kind used by Thom, Polach and Bowman (1978) in New South Wales is now required to establish the chronology in East Gippsland, and the similar sequence of events on other sandy sectors on the Victorian coast.

## CONCLUSIONS

The pattern of geomorphological changes on sandy shorelines in Victoria during the past century has been dominated by erosion, with only limited sectors showing progradation. Clearly, it is unwise to allow

subdivision and real estate development on low-lying sandy coasts threatened by such erosion. If shoreline recession continues, it will become necessary to use artificial nourishment to counteract the wastage of beaches in resort areas. It is difficult to establish precise rates of shoreline advance or recession from comparisons of early surveys and air photographs with the modern configuration, and there is a need for more accurate monitoring of future changes by means of repeated surveys along fixed transects across the coastal margin at selected points on the Victorian coast. The documentation of such data will be an important part of the scientific programme of a Coastal Management Authority in Victoria.

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# THE GEOLOGY AND METAMORPHISM OF THE BONNIE DOON AREA, VICTORIA

By G. N. PHILLIPS\* AND V. J. WALL†

**ABSTRACT:** The 2500 m Siluro-Devonian Bonnie Doon Formation, comprising mainly quartz sandstones and mudrocks, is conformably overlain by 250 m of lithic sandstone and conglomerate of the Glen Creek Lithic Sandstone north of Bonnie Doon. The oldest units outcrop in the west along the N-S trending Mt Easton Anticlinorium, while the Glen Creek Lithic Sandstone is confined to the Walhalla Synclinorium further east. These two formations are near the top of the Lower Palaeozoic Melbourne Trough sequence and have undergone low grade regional metamorphism producing monoclinic chlorite — 2M muscovite  $\pm$  carbonate assemblages. Metamorphism is interpreted to have been at very shallow depths requiring a high geothermal gradient, presumably associated with the onset of regional igneous activity. In the lithic sandstones, chlorite — carbonate assemblages formed instead of Ca-Al silicates as a result of significant  $p\text{CO}_2$  (partial pressure of  $\text{CO}_2$ ) during the regional event. Both sedimentary formations have been mapped within the aureole of the Late Devonian Strathbogie Granite, where four metamorphic zones are differentiated in pelitic metasediments: Spotted Zone, Biotite Zone, Cordierite-Muscovite Zone, Cordierite-K-Feldspar Zone. Granite intrusion took place under low confining pressure ( $\approx 0.5$  kb). During thermal metamorphism,  $p\text{H}_2\text{O} = p\text{Total}$  in the quartz-rich sandstones and mudrocks, but  $\text{CO}_2$  was an important fluid component in the impure limestone conglomerates and many lithic sandstones.

Gold is most strongly developed within the cordierite hornfels (often graphitic) near the Strathbogie Granite. It is finely disseminated through retrogressed pelites with rare quartz veins. Gold deposition from circulating aqueous solutions was associated with retrograde sericite alteration of surrounding host rocks.

## INTRODUCTION

Bonnie Doon is situated on the northern edge of the Melbourne Trough. The stratigraphy of this trough has been described further south near Eildon (Thomas 1947) and Warburton (VandenBerg 1975). Much of the Trough comprises a rather uniform quartz-rich flysch sequence of sandstones, mudstones and shales of several thousand metres thickness (Schleiger 1964). However, near Bonnie Doon a major change of depositional environment is evident near the top of the sequence, with the incoming of lithic sandstones, conglomerates and lesser calcareous lithologies (Fig. 1).

The relatively wide range of bulk rock compositions has made possible a larger variety of contact metamorphic assemblages than is usual in Melbourne Trough aureoles: cf. Morang (Edwards & Baker 1944), Lysterfield (Phillips 1976). This has allowed a detailed reconstruction of the contact metamorphic conditions, which, coupled with a concurrent study of the Strathbogie Granite (Birch *et al.* 1977) yields a clearer understanding of the emplacement of alumin-

ous (S-type) granites in Central Victoria (Phillips *et al.* in prep.). The Tallangalook gold mine within the Bonnie Doon contact aureole is unusual for Victoria in being a disseminated deposit, exhibiting few quartz veins and bearing a close spatial relationship to a major intrusion (Dunn 1917, Kenny 1937).

This study has three main aims:

1. an interpretation of the stratigraphy and structure at Bonnie Doon,
2. a detailed investigation of contact metamorphic conditions, and
3. the construction of a model for gold genesis at Tallangalook.

The study also provides an explanation for some of the differences between pelitic assemblages developed in contact aureoles of the Melbourne Trough, and those in Ordovician metasediments further west.

## REGIONAL GEOLOGY

The Melbourne Trough is a structural block containing mostly marine, Cambrian to Middle Devo-

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nian sediments (VandenBerg & Garratt 1976). Sandstones and mudstones (terminology of Ingram 1953) of Siluro-Devonian age predominate throughout the exposed sequence and marker horizons are typically rare.

The regional structure consists of a series of NNW trending folds (Williams 1964) of which the Mt Easton Anticlinorium and Walhalla Synclinorium are considered by us to be the most important structures near Bonnie Doon. Folding is generally correlated with the Late Devonian Tabberabberan Orogeny (Talent 1965).

Within the Trough, the oldest beds are exposed in the west at Costerfield and Deep Creek (VandenBerg & Garratt 1976). In these areas Lower Palaeozoic sedimentation appears to have ceased in the Late Silurian or Early Devonian whilst further east, sedimentation continued through the Early Devonian and well into the Middle Devonian e.g. at Eildon and Upper Yarra (Moore 1965). The youngest Trough sediments (Cathedral Beds and Koala Creek Beds) are found between the latter two areas. These observations suggest a filling of the Trough, beginning in the west, during the Early Devonian.

Two formations have been defined in the Bonnie Doon area (see Appendix) and to the north these are intruded by the 2000 km<sup>2</sup> massive Late Devonian Strathbogie batholith.

#### STRUCTURE

Between Bonnie Doon and the Strathbogie Granite, the major structures are an anticlinorium in the west and a synclinorium in the east (Fig. 1). The folds trend N-S, have variable but generally shallow

plunges and near vertical axial planes. The anticlinorium is the northward extension of the Mt. Easton Anticlinorium (Mt Easton Axis of Thomas 1947) mapped near Eildon (VandenBerg 1975); the synclinorium is the northward extension of the Walhalla Synclinorium that extends south past Woods Point.

Associated with these major structures are numerous open to isoclinal minor folds with locally overturned bedding. Whereas bedding is usually preserved, a weak axial plane cleavage is widespread in the finer lithologies. A NW-SE striking hinge fault cuts through the centre of the area, downthrowing sediments on the south.

The major structures can be traced into the contact aureole with some difficulty, and are abruptly truncated by the granite. The contact itself is sharp, and detailed mapping shows it is steeply dipping (Birch *et al.* 1977, Phillips *et al.* in prep.).

#### SEDIMENTARY PETROGRAPHY

##### *Quartz Sandstone*

The quartz sandstones consist of moderately sorted, subangular to rounded quartz grains (0.1-0.5 mm), that show variable degrees of grain boundary adjustment. Grains are often interlocking, have sutured edges and the rocks have no visible porosity. Angular feldspar and lithic fragments made up > 10% of some samples (Table 1).

Matrix material (5-20%) is mainly chlorite and elongate aggregates of white mica. The latter are bent around quartz grains and define a weak foliation parallel to bedding.

TABLE 1  
MINERALOGY OF MELBOURNE TROUGH SEDIMENTS: BONNIE DOON FORMATION AND GLEN CREEK LITHIC SANDSTONE.

	<i>Quartz Sandstone</i>	<i>Mudrocks</i>	<i>Lithic Sandstone</i>	<i>Conglomerate</i>
COARSE DETRITAL FRACTION	Quartz	Quartz	Quartz	Quartzite
	K-Feldspar	Mica	Feldspars* (5-20%)	Sandstone
	Na-Plagioclase		Shale (5-30%)	
	Granite (r)		Quartzite	
			Alt. Mafic Volcs	
MATRIX			Mica schist (r)	
	White mica	White mica	White mica	Quartz
	Chlorite	Chlorite	Chlorite	Sandstone
	Quartz	Carbonaceous matter	Carbonate (r)	Quartzite
	Tourmaline		Tourmaline	
CEMENT	Rutile (r)	Sulphides (r)	Carbonaceous matter	
	Calcite (XRD) (< 30%)	Carbonate (< 2%)	Carbonate	Silica
			Silica	Fe oxide (?weathering)

r = rare, \*: alkali and sodic feldspar.



### *Mudrocks (Mudstones, Shales)*

The mudstones consist of a silt sized, quartz-rich, clastic fraction set in a chlorite-white mica matrix. The shales contain mainly monoclinic chlorite and 2M muscovite (somewhat phengitic) with little quartz.

### *Lithic Sandstones*

The lithic sandstones have a variable texture and mineralogy. Most are poorly sorted, angular, coarse to fine sand varieties that lack fine scale bedding. Quartz and feldspar are the main framework components, along with common shale fragments up to 1 cm. The latter contain quartz, chlorite and white mica. Other lithic fragments comprise altered mafic volcanics, quartzites and micaceous schists. Matrix material is mainly chlorite and white mica.

### POST-DEPOSITIONAL MODIFICATION OF THE MELBOURNE TROUGH ROCKS

Since the younger sediments at Bonnie Doon appear to be near the top of the Melbourne Trough sequence, it is unlikely they were ever buried to a depth greater than 5000 m (see also later discussion). However, most of the sediments have undergone substantial post-depositional textural and mineralogical adjustments. The coarse grained sediments have undergone compaction and grain boundary adjustment which in extreme cases have partially obliterated the clastic nature of the rocks. The finer grained sediments show little adjustment of framework grains, but show a preferred orientation of phyllosilicates parallel to bedding within the matrix.

Mineralogical changes are most pronounced in the mudrocks and lithic sandstone matrix. From their present mineralogy the mudrocks have a bulk chemistry (Si, Al, K, Mg, Fe rich; Na, Ca poor) indicative of a quartz-illite-chlorite  $\pm$  montmorillonite  $\pm$  kaolinite sediment. The present mineralogy involves quartz and detrital white mica along with post-depositional chlorite, 2M white mica, carbonates, minor sulphide and carbonaceous material (Table 1). These secondary mineral assemblages and those from underlying Cambrian metavolcanics (see below) are compatible with upper zeolite-prehnite/pumpellyite grade regional metamorphic adjustment of the sequence (Frey 1970). Similar secondary assemblages have been noted elsewhere in the Melbourne Trough at Sugarloaf Dam-site, in Early Devonian-Silurian siltstones (Diprose 1976). The metamorphic adjustments presumably took place during burial and deformation associated with the Tabberabberan Orogeny.

Ordovician rocks outcropping 40 km southeast of Bonnie Doon on the Howqua River exhibit well developed slaty cleavage. This sequence abuts Camb-

rian (?) mafic volcanic and intrusive rocks which contain combinations of prehnite, pumpellyite and actinolite (Bailey 1974, Herrmann 1974). If these early Palaeozoic sequences are presumed to underlie the Melbourne Trough sequences, then low grade metamorphic assemblages in the Cambrian-Ordovician rocks may also reflect the Tabberabberan Orogeny. However it has not been conclusively demonstrated that the Siluro-Devonian rocks conformably overlie the Ordovician. Furthermore, mafic volcanic detritus in the Glen Creek Lithic Sandstone may have a Cambrian source (see below), pointing to uplift of greenstone belts before sedimentation ceased in the Melbourne Trough.

The absence from the Glen Creek Lithic Sandstone of calcsilicate phases characteristic of low grade metamorphic facies (e.g. zeolites or pumpellyite) may be due to the activity of carbon dioxide. Even at low  $p\text{CO}_2$ , these phases are unstable relative to carbonate-chlorite assemblages (Zen 1961) such as those at Bonnie Doon and Sugarloaf Dam (Diprose 1976). However, the presence of sphene in the secondary mineral assemblages of the sediments indicates that  $p\text{CO}_2$  was below that required for the development of rutile + calcite (Hunt & Kerrick 1977). The absence of hematite and the common presence of sulphides suggest generally reducing conditions during the low grade regional adjustment.

### DEPOSITIONAL ENVIRONMENT

The sedimentary structures, absence of fossils and textural immaturity of the coarser sediments at Bonnie Doon suggest deposition from turbidity currents as envisaged by Schleiger (1971). The large proportion of mudstone and shale in the Bonnie Doon Formation further suggests distal deposition with significant periods of intervening pelagic sedimentation. The conglomerates near the top of the sequence mark a change from quartz-rich flysch (Bonnie Doon Formation) to an intermediate flysch (Glen Creek Lithic Sandstone). There is no evidence of shallowing of water depth, and we favour an allochthonous origin for the limestone conglomerate. The quartz-rich conglomerate at the base of the Glen Creek Lithic Sandstone is also surrounded by deep water flysch sediments and may represent a submarine channel deposit.

### PROVENANCE

The quartz-clay rich, pre-burial character of the Siluro-Devonian sequence suggests that the source area for these sediments comprised older granitic plus sedimentary and/or metamorphic terranes. Such areas may have been exposed to the west and south of the Melbourne Trough, though the picture is less clear to

the east. Although the surrounding Lower Palaeozoic sequences have provided some detritus (e.g. Cambrian (?) altered mafic volcanic fragments, Ordovician slate fragments) for the Glen Creek Lithic Sandstone, the Lower Palaeozoic contribution to the bulk of the sequence is not readily apparent. A pre-Ordovician terrane to the west and/or south of the Melbourne Trough seems the most likely source area, in accord with palaeo-current directions (Couper 1965). This could have contributed the bulk of the quartz and clays and also the rarer mica schist fragments. Studies of assemblages from gneissic xenoliths in Central Victorian igneous bodies have suggested an underlying high grade regional metamorphic terrane e.g. sillimanite-garnet, sillimanite-biotite-ilmenite, cordierite-spinel from the Violet Town Volcanics, cordierite-ilmenite, sillimanite-spinel-garnet from the Strathbogie Granite (Birch *et al.* 1977) and Cerberean Cauldron (Birch & Gleadow 1974).

The Siluro-Devonian pelites such as those at Bonnie Doon have higher chlorite/mica ratios than Ordovician pelites. The younger rocks are hence generally less aluminous with higher (Fe + Mg)/Al. This suggests that the source area of the Early Devonian sediments may have been less intensively weathered

than that of the Ordovician sediments leading to less degraded clay assemblages — perhaps resulting from cooler climates and Australia's poleward post-Ordovician movement (Embelton *et al.* 1974).

## CONTACT METAMORPHISM

### PETROGRAPHY

A broad contact metamorphic aureole (up to 3 km wide) developed north of Bonnie Doon along the margin of the Strathbogie Granite (Phillips *et al.* in prep.). This batholith comprises mainly massive cordierite-biotite granites and has sharp steeply dipping contacts with the surrounding hornfelses. K/Ar dating of the granites gives cooling ages of  $365 \pm 5$  my. (Richards, J. R., pers. comm. 1975).

Four metamorphic zones have been mapped in pelitic lithologies: (a) Spotted, (b) Biotite, (c) Cordierite-Muscovite, (d) Cordierite-K-Feldspar. Assemblages observed in these zones are listed in Table 2.

*Spotted Zone:* The first mesoscopic signs of contact metamorphism are spotting on the bedding planes of pelites. The spots are marked by slight modal increase

TABLE 2  
PROGRADE CONTACT METAMORPHIC ASSEMBLAGES IN SILURO-DEVONIAN SEDIMENTS ADJACENT TO  
THE STRATHBOGIE GRANITE, NORTH OF BONNIE DOON.

	<i>Spotted Zone</i>	<i>Biotite Zone</i>	<i>Cord-Musc Zone</i>	<i>Cord-Kfs Zone</i>
PELITIC	Musc-Chl-Qtz $\pm$ Tour, Opaq.	Bi-Musc-Chl-Qtz $\pm$ Tour, Fe oxide, Sulphide, Zircon, Graphite, Na Plag.	Cord-Musc-Bi-Qtz- Tour-Opaq.	Kfs-Cord-Bi-Tour-Qtz- Opaq. $\pm$ Musc
PSAMMITIC	Musc-Qtz $\pm$ Tour	Musc-Qtz $\pm$ Tour, Bi	Musc-Qtz $\pm$ Tour, Bi	Musc-Bi-Tour-Qtz
CALCAREOUS	Not present	Diop-Cc-Plag Diop-Cc-Opaq-Qtz Diop-Cz-Opaq-Qtz Diop-Act-Sph-Qtz Diop-Plag-Op-Qtz Act-Cc-Op-Qtz Act-Plag-Ilm-Qtz-Bi	Diop-Trem-Opaq-Qtz Diop-Plag-Ilm-Qtz Diop-Cc-Plag-Qtz Diop-Cc-Op-Qtz Diop-Woll-Cc-Qtz Diop-Woll-Cc-Opaq Diop-Act-Qtz Diop-Act-Cc Act-Bi-Plag-Ilm-Qtz Act-Cc-Qtz Woll-Scap-Cc-Sph Woll-Diop-Vesuv-Qtz	Not present

#### KEY

Bi = Biotite	Tour = Tourmaline	Ilm = Ilmenite	Scap = Scapolite
Musc = Muscovite	Opaq = Opaque phase	Diop = Diopside	Sph = Sphene
Qtz = Quartz	Cord = Cordierite	Cc = Calcite	Trem = Tremolite
Chl = Chlorite	Plag = Plagioclase	Act = Actinolite	Vesuv = Vesuvianite
	Kfs = K-Feldspar	Woll = Wollastonite	Cz = Clinozoisite



of chlorite, muscovite and opaque minerals. Neighbouring psammities retain their sedimentary and regional metamorphic microstructure. The Spotted Zone is up to 800 m wide.

**Biotite Zone:** Biotite-rich hornfelses with minor muscovite and chlorite are typical of this zone. Muscovite and fawn brown biotite have grown parallel to the poorly defined bedding. Calc-silicate phases occurring in the lithic sandstones include calcite, diopside, actinolite, tremolite, clinozoisite and plagioclase. Relict clastic microstructures are preserved and most of the metamorphic phases are fine grained (< 1 mm). The Biotite zone is up to 1.5 km wide.

**Cordierite-Muscovite Zone:** Within 1000 m of the granite, cordierite porphyroblasts up to 2 mm in diameter are abundant in pelitic hornfelses. These porphyroblasts are sector twinned with inclusions of biotite, quartz, muscovite and opaque minerals. The biotite has a similar habit to that of lower grade rocks, but is a medium brown colour in thin section. Psammities are typically well recrystallized exhibiting polygonal quartz grains and a weak inherited foliation defined by muscovite and biotite.

The impure limestone conglomerate, which forms a 50 m long pod, contains 5 mm by 15 mm calcareous lenses set in a more siliceous matrix. The lenses are flattened parallel to bedding, are wollastonite-rich and commonly have calcite cores. Quartz is rare but may coexist with wollastonite and calcite. The siliceous matrix contains diopside, scapolite, vesuvianite and quartz with rare shale fragments. The grain size within the calcareous and siliceous area is fine (< 1 mm).

**Cordierite - K-feldspar Zone:** Perthitic K-feldspar is found in fresh cordierite hornfelses within 100 m of the granite, marking the highest grade zone in the aureole. Muscovite is less abundant than at lower grades and chlorite is absent. In this zone, especially around the Golden Mountain quarries at Tallangalook, much pelite has been retrogressed to sericite-rich assemblages.

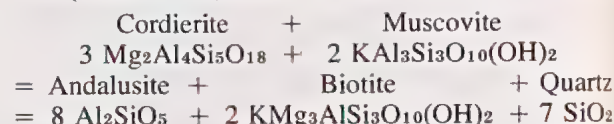
#### PETROGENESIS

The prograde metamorphic zonal pattern found in the Bonnie Doon aureole has long been recognised from other aureoles, e.g. Comrie (Tilley 1924) and Bulla (Tattam 1925). The abundance of cordierite and lack of garnet in these aureoles is evidence of pressures substantially less than commonly found in regional metamorphism.

However the Bonnie Doon assemblages differ slightly from those found in Ordovician hornfelses in

west-central Victoria. At Bendigo (Beavis 1962) and at Charlton, andalusite is associated with cordierite-muscovite-biotite hornfelses in Ordovician thermal aureoles. AFM and A'KF projections of these four phases in the presence of quartz (Fig. 2, 3) show that cordierite-muscovite assemblages can be chemically equivalent to biotite-andalusite assemblages. Thus the occurrence of andalusite assemblages could reflect differing p-t conditions. In highly aluminous metasediments andalusite may form with or without biotite, regardless of bulk rock Fe: Mg ratios.

In the Fe-free system  $K_2O$ - $MgO$ - $Al_2O_3$ - $SiO_2$ - $H_2O$  (Seifert 1970, Bird & Fawcett 1973), the reaction:



has a large negative  $\Delta V$  term ( $-3.013$  cal/bar, Robie & Waldbaum 1968). As such, muscovite-cordierite would be the low pressure assemblage. From experimental studies biotite-andalusite-quartz would be favoured by higher pressure and temperature (Seifert 1970).

With the introduction of Fe, this reaction becomes divariant and cordierite-muscovite is restricted to even lower p and t. Thus three main factors favour the occurrence of andalusite in pelitic hornfelses: (1) highly aluminous compositions, (2) higher p and/or t within the andalusite stability field, (3) high Fe/Mg ratios. Bulk chemical and temperature controls on mineralogy are evident in some aureoles e.g. Bendigo (Beavis 1962), but the effect of pressure is difficult to assess while accurate pressure data within many aureoles are unavailable.

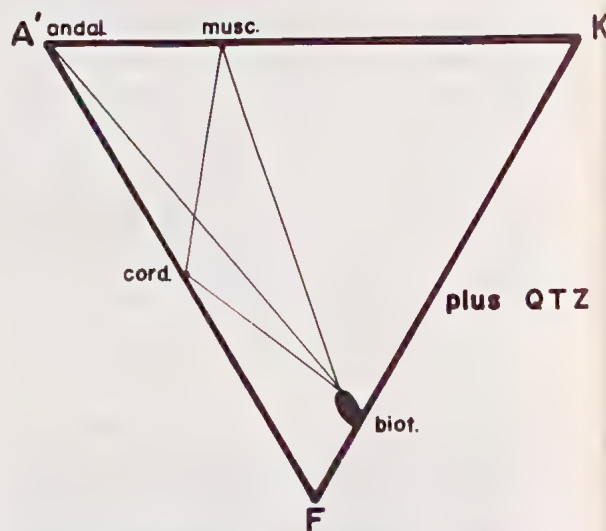


Fig. 2.—A'KF diagram illustrating the equivalence of biotite-andalusite and muscovite-cordierite assemblages.

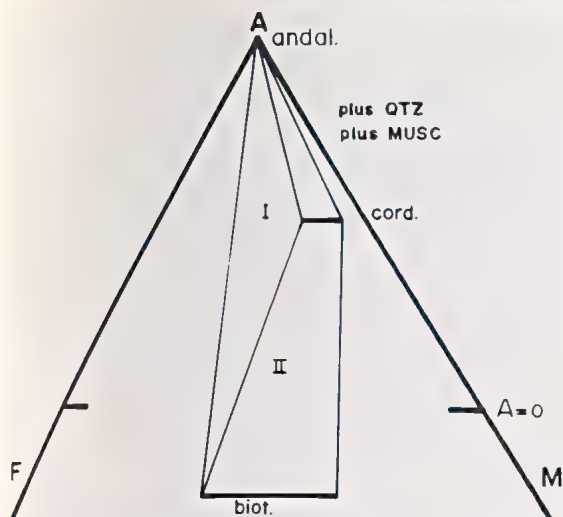


Fig. 3.—AFM diagram for Cordierite-Muscovite zone, showing the compositional field of andalusite-cordierite-biotite-muscovite-quartz (I) and the same assemblage without andalusite (II).

**Pressure:** A reasonable estimate of pressure within the Bonnie Doon aureole can be made from stratigraphic cover criteria, but the metamorphic assemblages offer little additional quantitative information. Two lines of stratigraphic evidence are available: the Violet Town Volcanics and the Siluro-Devonian sediments.

The Violet Town Volcanics abutting the northern margin of the Strathbogie Granite exhibit contact metamorphic effects. The granite intrudes the rhyodacite ignimbrite well above the base of the volcanic sequence. Hence this portion of the granite solidified at shallow depth — perhaps less than 1000 m. Providing there has been no large post-granite emplacement movement, the present Bonnie Doon aureole may represent structural levels only 500-1000 m below this.

The youngest sedimentary units exposed at Bonnie Doon (upper part of the Glen Creek Lithic Sandstone) are correlated with the Early-Middle Devonian Norton Gully Sandstone, which is itself near the top of the Melbourne Trough (VanderBerg & Garratt 1976). East of Bonnie Doon and in the Cathedral Range to the south, younger Devonian sediments overlie the Norton Gully Sandstone but these do not exceed 2000 m thickness (VanderBerg & Garratt op. cit.). Since the Strathbogie Granite (Late Devonian) has closely followed the cessation of sedimentation and the deformation of the Melbourne Trough sequence (Middle-Late Devonian) the likely depth of intrusion is therefore less than 2000 m. Thus stratigraphic considerations indicate aureole pressures of less than 1 kb, possibly less than 0.5 kb. Under such low confining pressures, the typical shallow positive slope (dp/dt) of

dehydration reactions would place these reactions at relatively low temperatures.

**Temperature:** High level intrusions are often associated with quite small aureoles since the surrounding country rocks are rather cool, yet the aureole around the Strathbogie Granite is up to 3 km wide. Detailed mapping at several places with up to 500 m relief repeatedly indicates a steep to vertical granite contact.

Phase equilibria give some indication of the likely temperature maximum, and its distribution in the contact aureole during intrusion. Within the pelites two isograds are particularly useful for estimating temperature: (1) the incoming of cordierite-muscovite, (2) the incoming of cordierite — K-feldspar. The temperature ranges for the Spotted Zone and Biotite Zone in other aureoles have been estimated by Turner (1968) and are included here (Fig. 4).

The breakdown of chlorite-muscovite-quartz assemblages has been studied by Seifert (1970), Hirschberg and Winkler (1968) and Bird and Fawcett (1973). Seifert, and Bird and Fawcett ran experiments in the Fe-free system and their results are mainly of qualitative interest here. Hirschberg and Winkler produced cordierite in unreversed runs at: 0.5 kbars  $\approx$  525° C, 1.0 kbars  $\approx$  515° C. The formation of cordierite — K-Feldspar assemblages has been studied by Haack (in Winkler 1967, p. 74). According to Winkler, temperatures for the reaction: Muscovite + Biotite + Quartz = Cordierite + K-Feldspar + H<sub>2</sub>O are similar to the muscovite-quartz breakdown, i.e.: 0.5 kbars 580  $\pm$  10° C, 1.5 kbars 600  $\pm$  10° C. Obviously the muscovite-quartz breakdown places an upper temperature limit on the muscovite-biotite-quartz reaction, and hence cordierite formation by this reaction.

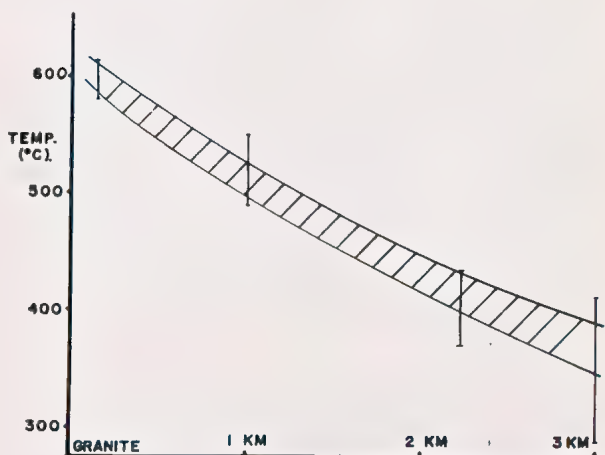


Fig. 4.—Maximum temperature in the Bonnie Doon contact aureole vs. distance from the Strathbogie Granite.



Jaeger (1957) calculated the theoretical temperature distribution around cooling intrusive bodies. According to his model, the Strathbogie Granite can best be approximated as a large ( $1^+$  km wide) granite body intruded into fluid-saturated sediments. To form such a large aureole with a contact temperature of 550–600°C requires an elevated country rock temperature (250–300°C) prior to intrusion. At an average geothermal gradient of 20°C/km the sediments would not have reached 100°C during burial. This suggests that the geothermal gradient in this part of the Melbourne Trough was significantly higher than average during the Late Devonian period of acid igneous activity, culminating in acid plutonism and volcanism.

#### *Activities of Volatiles during Contact Metamorphism:*

In the absence of data to the contrary, fluid pressure is regarded as approximating the total pressure for the following discussion.

The mineralogy of the mudstones and quartz sandstones suggest that a water-rich fluid phase existed in these lithologies during contact metamorphism. Variable but minor dilution by  $\text{CO}_2$  and  $\text{CH}_4$  seems likely, due to the oxidation with contact metamorphism of carbonaceous matter in the metasediments.

The local presence of carbonaceous material, the absence of hematite and the rarity of magnetite in the hornfelses imply generally low oxygen fugacities during contact metamorphism. More substantial dilution of aqueous fluids by  $\text{CO}_2$  prevailed in the lithic sandstones and limestone conglomerate. The assemblage diopside and tremolite-calcite-quartz from the one locality imply locally varying  $p\text{CO}_2$ . In the Cordierite-Muscovite Zone, wollastonite bearing assemblages are common in the impure limestone conglomerate. Usually wollastonite forms a reaction layer between calcite lenses and the siliceous matrix, but where calcite-wollastonite-quartz coexist,  $x\text{CO}_2$  limitations are implied.

Experimental studies with wollastonite (Harker & Tuttle 1956, Greenwood 1967) show the temperature of formation to be strongly dependent on fluid composition i.e.  $x\text{CO}_2$ . The apparent stable coexistence of wollastonite-calcite-quartz at some places and the presence of wollastonite or quartz-calcite at others within the one thin section, may indicate a variable  $x\text{CO}_2$  over a few centimetres. Suggested limits for 550°C are: Wollastonite  $x\text{CO}_2 < 0.3$ , Calcite-Quartz  $x\text{CO}_2 > 0.3$ .

#### GENESIS OF THE GOLD DEPOSITS

Apart from minor amounts of cassiterite, the only significant mineralization around Bonnie Doon is gold. The major production came from the Golden

Mountain quarries at Tallangallook, totalling in excess of 142 kg of gold (Dunn 1917, Kenny 1937, Bowen 1974). Although gold mineralization is largely confined to the metasediments, major occurrences bear close spatial relationship to the Strathbogie Granite. Both the Tallangallook quarries and the Black Ore mine further west are within cordierite zone hornfelses and the only cordierite-K-feldspar assemblages have come from drill cores from the former location. Marginal dykes are present in some workings.

Tallangallook is situated on the nose of a broad, north-plunging anticline within 100 m of the granite. The bedding dips at 60–70° N towards the granite contact, which is sharp, steep, and associated with minor aplite dykes. Lithologies include cordierite-rich hornfelses, quartzites and some carbonaceous hornfelses, most of which are quite retrogressed. Gold occurs as fine disseminated grains with arsenopyrite and pyrite in carbonaceous pelites and on quartz films (Kenny 1937, Baragwanath 1937). Values were apparently lower in adjacent siliceous hornfelses. Throughout all the quarries and small mines, quartz veins are minor and bear no obvious relationship to higher gold grades.

Although the Melbourne Trough sediments are overall not particularly auriferous (Bowen 1974, Glas-son & Keays 1978), it appears likely that they contributed to the Tallangallook mineralization. The outcropping granite is generally not marked by high gold values, whereas the Tallangallook stratigraphic horizon has small mining pits even out of the contact aureole. Our proposed model of gold genesis involves remobilization of gold by granite-initiated, circulating aqueous fluids followed by deposition at reducing sites, particularly at or near graphitic hornfelses. The widespread retrogression at Tallangallook may result from these aqueous fluids. The steep dip of the bedding towards the granite and/or the N-S faults may have provided a structural control over fluid movement.

#### APPENDIX

##### STRATIGRAPHY — MELBOURNE TROUGH ROCKS BONNIE DOON FORMATION

*Derivation:* Bonnie Doon town (985015, Alexandra, 1:100,000).

*Type Section:* North shore of Lake Eildon (939023 to 977020, Alexandra).

*Lithologies:* Quartz sandstone, siltstone, shale and rare limestone conglomerate.

*Thickness:* At least 2500 m, type section.

*Age and Relations:* This formation is the oldest exposed in the area and outcrops west of Dry Creek Road (Bonnie Doon to Tallangallook Road on Fig. 1) along the Mt. Easton Anticlinorium. The base is unexposed



but the top is marked by the incoming of conglomerates and lithic sandstones of the Glen Creek Lithic Sandstone above discontinuous dark shales.

The formation consists of a series of alternating massively bedded, dark green-grey mudstones and shales. Cross bedding (up to 2 cm) and graded bedding are common, while flame structures and ripple marks are found locally. The quartz sandstones weather to a red-orange colour in contrast to the brown-green weathered mudstones. Outcrop is poor except in the more massive sandstones.

On lithological similarities and general stratigraphy, the Bonnie Doon Formation is correlated with the Bullung Siltstone, Sinclair Valley Sandstone (both Middle-Late Silurian), Whitelaw Siltstone, Eildon Sandstone and Wilsons Creek Shale (all Early Devonian) of Thomas (1947) and VandenBerg and Garratt (1976). Quartz sandstone outcropping 1.5 km west of Bonnie Doon in the core of the Mt. Easton Anticlinorium may be equivalent to the McAdam Sandstone of VandenBerg and Garratt. This unit does not outcrop north of Lake Eildon.

#### GLEN CREEK LITHIC SANDSTONE

*Derivation:* Glen Creek (021031, Alexandra).

*Type Section:* (011075 to 027074, Euroa, 1:100,000).

*Lithologies:* Lithic sandstone, quartz sandstone, siltstone, shale and oligomictic conglomerate.

*Thickness:* 250 m, type section.

*Age and Relations:* The Glen Creek Lithic Sandstone conformably overlies the Bonnie Doon Formation and outcrops in the major synclinorium east of Dry Creek Road. The base of the formation is marked by discontinuous conglomerate lenses and lithic sandstone. The formation is overlain by unnamed mudstones to the east. Whereas poorly bedded, grey-green quartz sandstones and mudstones predominate, conglomerate and several units of grey lithic sandstone form mappable horizons. These latter are only 1-10 m thick but are usually continuous for hundreds of metres. On lithological grounds, the Glen Creek Lithic Sandstone is correlated with the Norton Gully Sandstone of the Walhalla Group (VandenBerg 1975). As in the Bonnie Doon Formation, lack of fossil evidence makes this correlation tentative.

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## PLEISTOCENE SUBMERGED CLIFF OFF THE OTWAY COAST OF VICTORIA, AUSTRALIA

By EDMUND D. GILL\*, E. R. SEGNI<sup>†</sup>, AND IAN HUNT<sup>‡</sup>

**ABSTRACT:** A submerged cliff with its base at ~45 m has been traced for about 20 km on the Otway continental shelf. Sonar traces show that the declivity of the shelf increases appreciably seaward of the cliff. Rock outcrops are extensive (~20%) on the shelf landward of the cliff, while seaward of it the shelf is covered with sediments. The cliff coincides with a change in basement depth determined in a geophysical survey, and appears to be a fault trimmed during a eustatic 'stillstand'. Beach calcarenite from a clifftop site at ~42 m dated 14 830 yr BP by <sup>14</sup>C assay.

### INTRODUCTION

There is a sharp contrast between the strongly dissected eastern flank of the Otway Ranges and the flat continental shelf of Bass Strait. Nevertheless there are significant features offshore between Cape Otway and Point Roadknight (Fig. 1), which are the concern of this paper.

### CONTINENTAL SHELF

Ten traverses with a Furano 250 echo-sounder were made (by I.H.) normal to the coast (Fig. 2). The gross vertical exaggeration conceals the flat nature of the shelf here; the actual declivities shown by traverses A1-10 are respectively 1 in 95, 110, 156, 155, 131, 97, 142, of the Otway Range of 1 in 16, 21, 2, 5 (in Tertiary terrain), 3, 3, 3, 6, 9 and 6 (in Cretaceous terrain). Thus the land slopes are about 15 times greater, reflecting the different geomorphic processes and history of the two.

Echo-sounding, fishing and scuba diving have revealed the following general characteristics of the sea floor under study. The only major break is a submerged cliff about 20 km long from off the Sugarloaf to off Point Roadknight (Fig. 2). The shelf is steeper seaward of the cliff than landward in its vicinity. In the shallower waters are rocky outcrops and boulder beds which are worked for crayfish. Thin silt and sand beds with eel grass, where fish are netted, occur between the George and Wye Rivers, and off Big Hill, at depths of 13-23 m. Fish frequent the water upwelling along the submerged cliff and this is why it is well known to

professional fishermen. Describing a similar submerged Pleistocene cliff near Plymouth in England, Cooper (1948) writes, 'the fish are reminiscent of birds soaring above a cliff in an ascending current of air'.

One of us (I.H.) has noted that about 20% of the seafloor between the submerged cliff and the shore consists of rock outcrops, and the sediments (where present) are thin and predominantly siliceous. Off the Cumberland River there is a bed of extra large boulders. Submerged islands occur off Cape Otway. By contrast, the shelf seaward of the cliff is covered with sediments, and rock outcrops are rare.

### SUBMERGED CLIFF

This feature can be traced (although not always clearly) for some 20 km (Fig. 1). It is not a straight line, but is approximately parallel to the coast. The height of the cliff varies, but 7 m is an average. Ramparts in two places on the top of the cliff have been described by fishermen. The submerged cliff can be seen particularly clearly in profiles A3, 5, 6 and 9. The varying direction, height, base and geomorphic definition are comparable with those on the existing coast. The marine transgression that submerged the cliff has depressed its morphology. The most irregular sections are those nearest the present coast, viz. near Point Roadknight, Point Grey and Point Hawdon. On the present coast the cliff base varies from low water level to 7 m above it (e.g. Mount Defiance), but the cliff base is usually within 4 m. The spring tidal range is 1.75 m in this area. Platforms graded to low water

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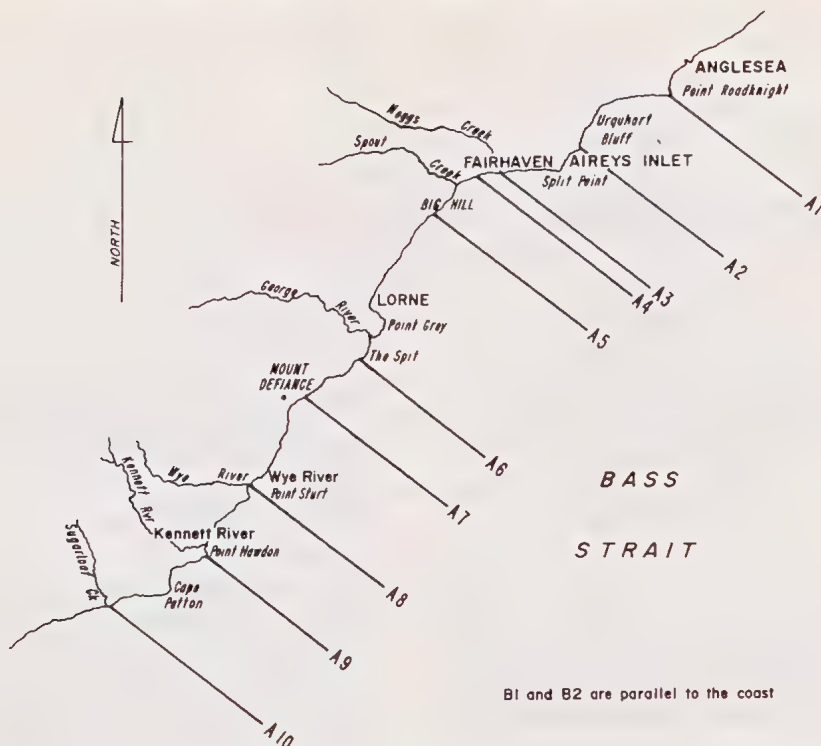


Fig. 1.—Map of sonar traces over the Otway continental shelf, Victoria.

level have been cut in Otway siltstone, but the greywacke is more resistant (Gill 1973), resulting in the range of level of the cliff base given above. As sea level is at the lower limit of this range, the same relationship may be inferred for the submerged cliff. That is, it was cut when sea level was of the order of 45 m lower than now. This level was determined where the  $^{14}\text{C}$  sample was collected, more accurate information being available there.

#### SUBMERGED BEACHES

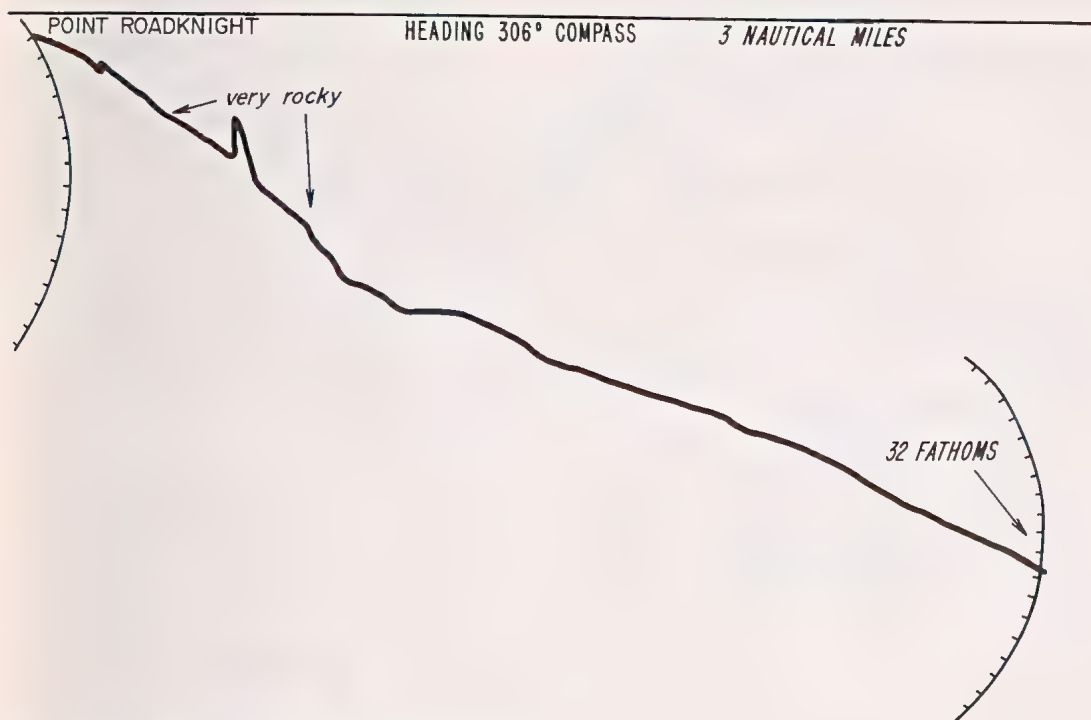
Both on top of the submerged cliff and at its base are layers of calcarenite, which are interpreted as relict beaches. One of us (I.H.) obtained some 20 pieces from the top of the cliff at a depth of about 23 fathoms (−42 m) about 5.6 km southeast of the mouth of Godfrey Creek, which is southwest of Lorne. The pieces were up to 23 cm in diameter (a size that could be brought up in fishing nets), irregular in outline, and platy (up to 8 cm thick). The surface was irregular and numerous voids were present as a function of incomplete cementation. Top and bottom could be readily distinguished by the colour (lighter on top) and the encrusting organisms. The tops were off-white (Munsell about 10YR 6/6) to pale brown (10YR 7/2).

The bottoms were brownish yellow (10YR 6/6) to strong brown (7.5YR 5/4 to 5/6) dry. These are oxidation colours.

The encrusting growths on top included seaweeds, sponges, bryozoa, calcareous worm tubes of two kinds, and a solitary coral. One species of bryozoan with an erect, rigid, rather fan-shaped colony was determined by Mr. Michael Cooper of the Department of Geology, University of Melbourne, as *Adeona grisea* (MacGillivray). The fauna of the undersurface was less rich, but included encrusting bryozoa and calcareous algae, calcareous worm tubes of two kinds, and a secondarily cemented spinose mollusc. The rock consisted mainly of sand-sized particles, including Foraminifera, but also of fragments of molluscs, cidaroid spines and bryozoan colonies.

One of us (E.R.S.) made a mineragraphic study of a sample, and found it to be a porous limestone composed mainly of detrital particles which include quartz, feldspar, minor biotite and occasional small particles of shale. The rock is estimated to be about 50% calcite, occurring as individual grains, finely crystalline, in many cases clearly organic in origin. The whole is loosely cemented by later carbonate, which is present as more transparent rims around calcite grains, or as cement between other mineral grains.

# A1 POINT ROADKNIGHT



# A2 URQUHART'S BLUFF

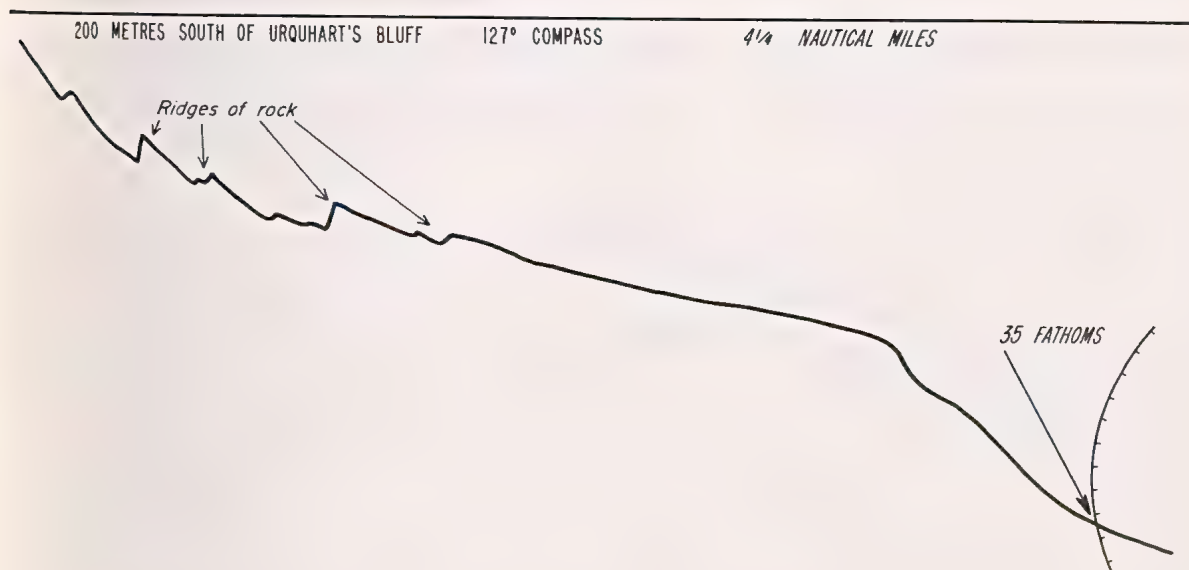
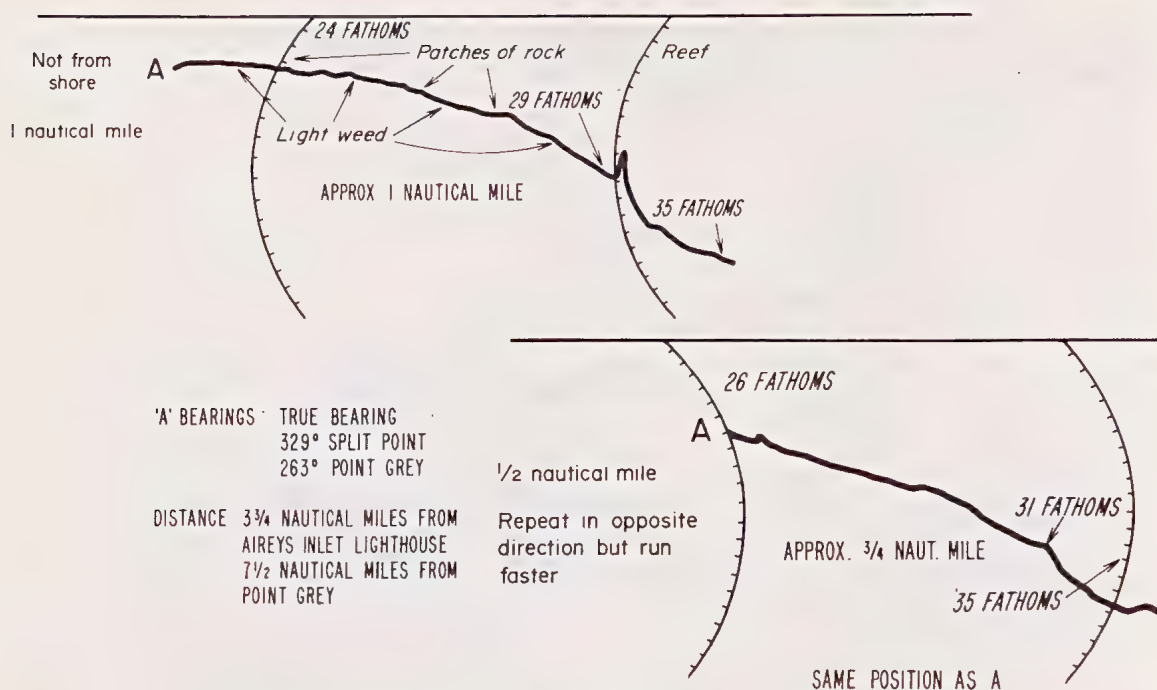


Fig. 2.—Sonar traces A1-10 (as shown in Fig. 1) run normal to the coast on compass courses, but not corrected for drift. A3 has two traverses run close to one another to show the variation in seafloor morphology.



## A3 OFF FAIRHAVEN



## A4 BETWEEN SPOUT CREEK AND MOGGS CREEK

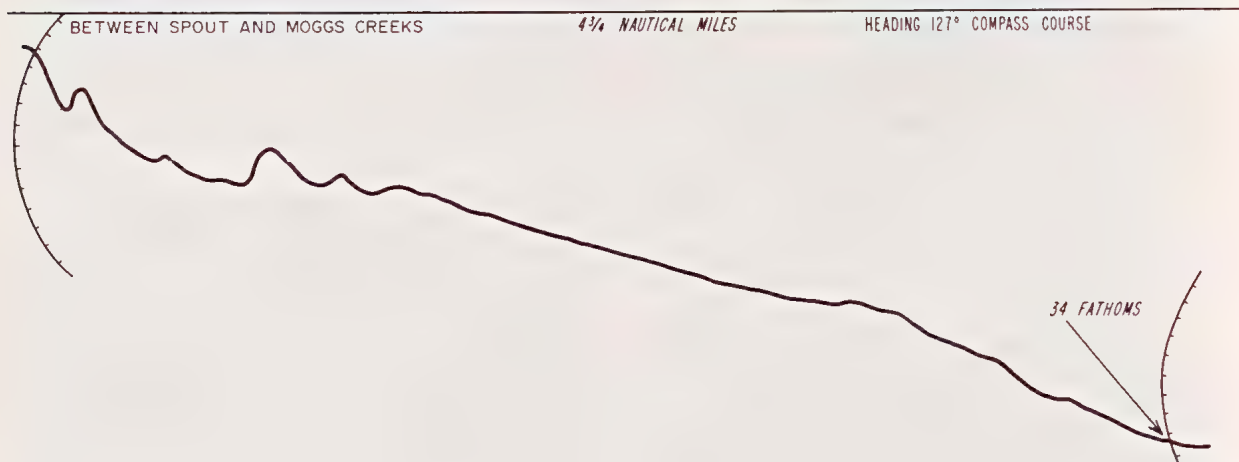
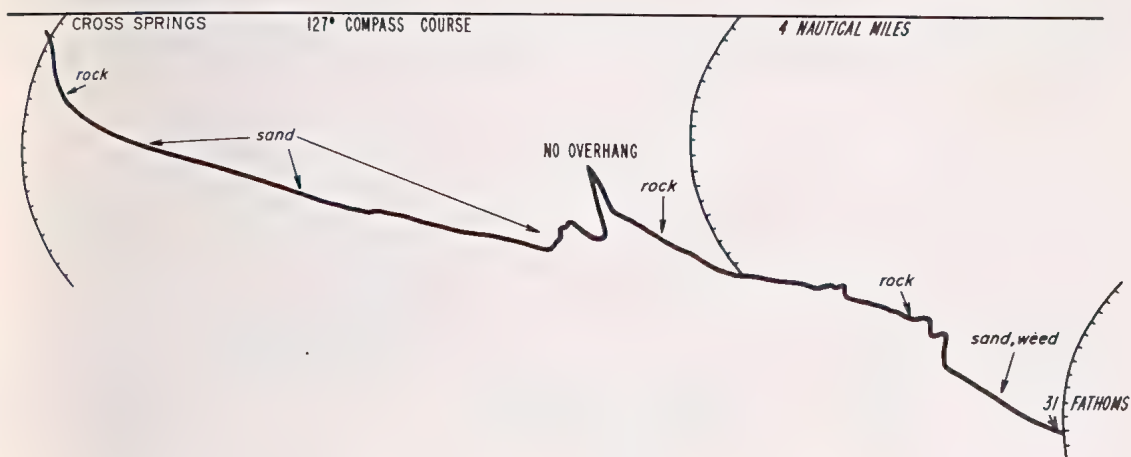


Fig. 2 (continued) Sonar traces A3-4

## A5 CROSS SPRINGS



## A6 GEORGE RIVER

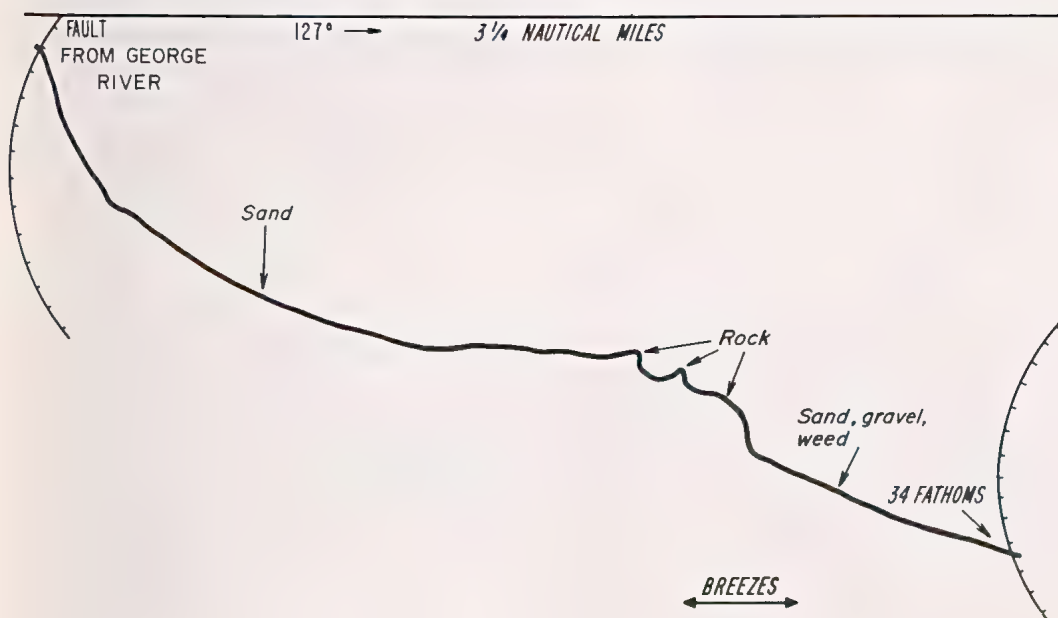
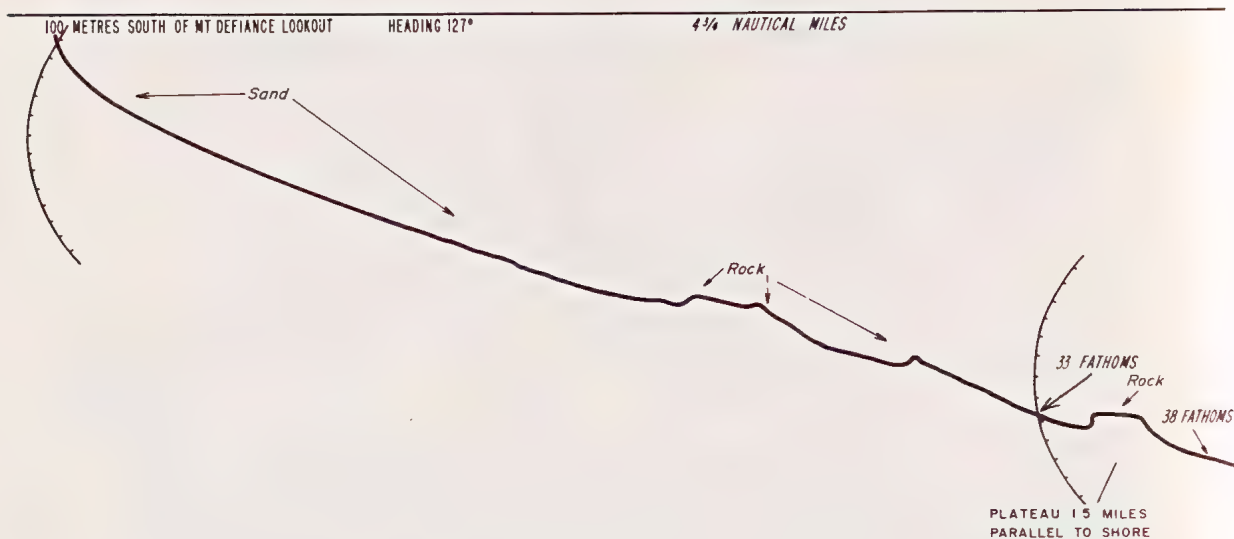


Fig. 2 (continued) Sonar traces A5-6



## A7 MOUNT DEFIANCE



## A8 WYE RIVER

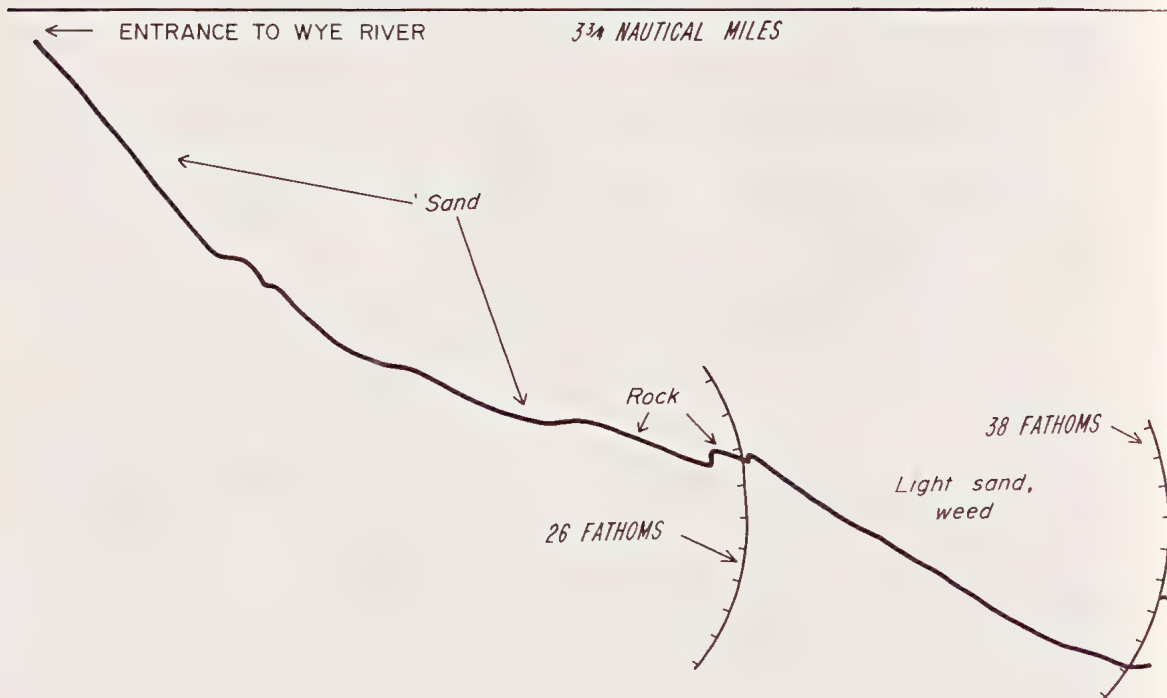
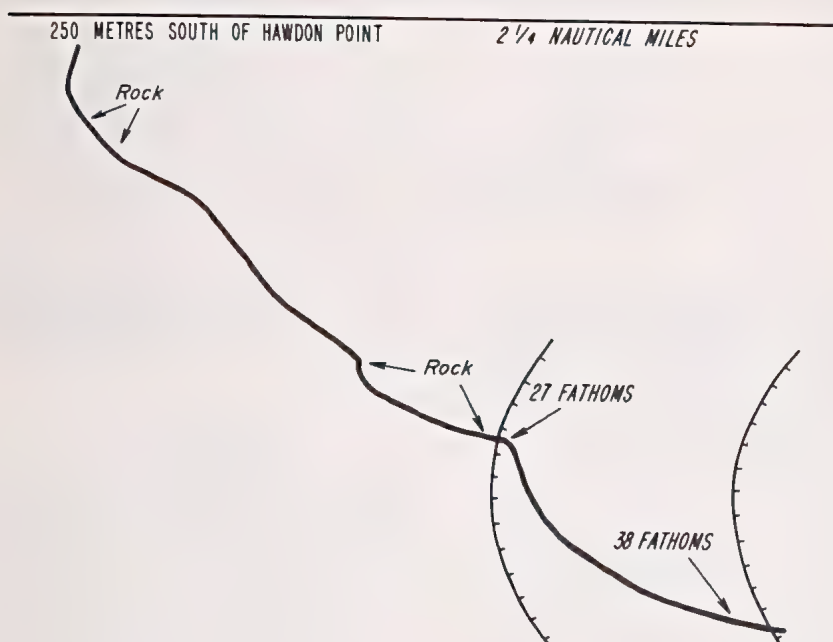


Fig. 2 (continued) Sonar traces A7-8

# A9 SOUTH OF POINT HAWDON



# A10 SUGARLOAF

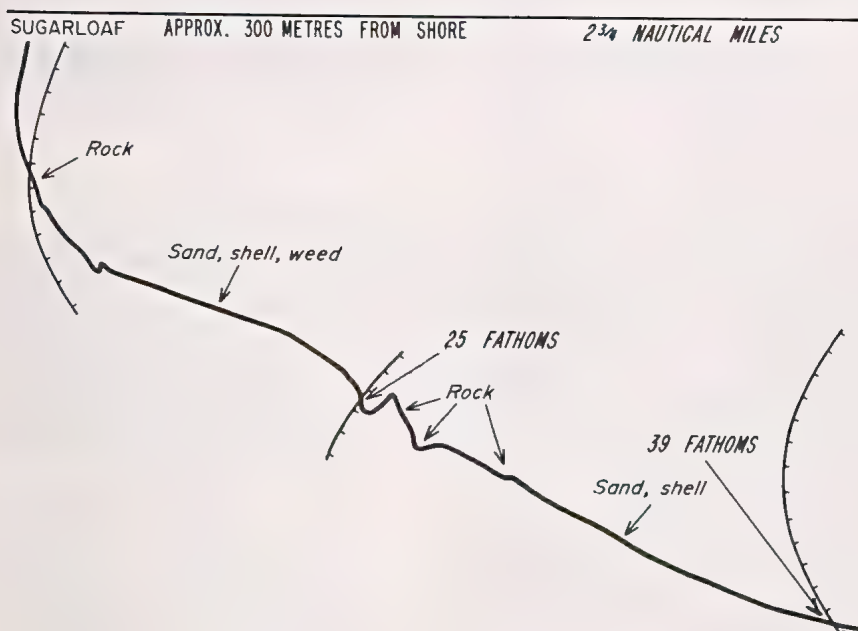


Fig. 2 (continued) Sonar traces A9-10



## B1 LORNE TO FAIRHAVEN

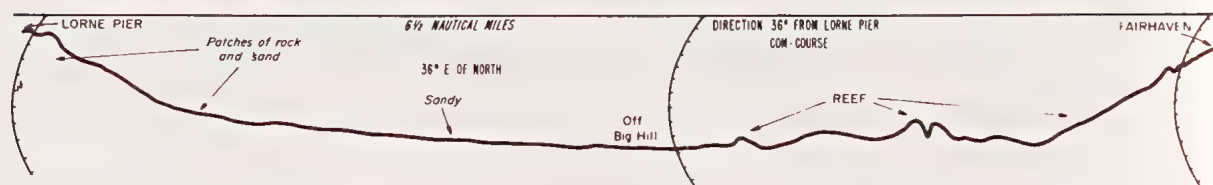


Fig. 3.—Sonar trace B1 parallel to the shore from Lorne to Fairhaven.

The geology and mineragraphy are consistent with a beach rock formed by freshwater seeping into carbonate beach sands, as occurs along the present coast. This is not to be confused with the beach rock of tropical shores. Other sediments seen so far from the seafloor in this region are predominantly siliceous.

### RADIOCARBON DATING

A second reason for the mineragraphic investigation was to determine whether the rock was suitable for radiocarbon dating, as there was insufficient included shell for this purpose. As the calcite rims were of the order of 0.002 mm only, it was estimated that the secondary calcite was less than 2% of the total carbonate present. The largest piece of rock was reduced to half its size by dissolution in an acid bath, to ensure that all penetrating crevices were removed. The sample so obtained was submitted to the Radiocarbon Laboratory of the University of Sydney, which assayed a date of  $14\,830 \pm 185$  yr (SUA-553). If the sample was formed as a beach rock when the sea was at that level, then the secondary carbonate is of similar antiquity to the beach, and does not alter the age. Even if it is not, the percentage of this carbonate is so low that it cannot grossly affect the result. On the Otways coast carbonate sediments do not persist because of their small volume and the appreciable rainfall. For example, the Last Interglacial (c. 125 000 yr) shoreline deposits are completely leached of carbonates. The sample assayed no doubt had some recycled carbonate, but if so it must be Flandrian (in the wide sense) in age. Any veneer of carbonate sediments left on the continental shelf as the sea retreated during the Last Glacial would be leached away before sea level rose again. This contrasts with the Warnambool area of Western Victoria, where quantitative work has shown that the majority of the shoreline carbonate has been recycled from the Pleistocene because of the high erosion rate (4 cm/yr) of the calcarenite cliffs (Gill 1973).

Jennings (1959) has recorded a similar submerged cliff in Bass Strait near King Island.

### INTERPRETATION

The submerged cliff varies in direction between southwest and west-southwest, while off Mount Defiance it is scalloped in plan, as the professional fishermen have observed. It is not simply a straight fault line. However, the present coast is remarkably straight overall, and is related to the direction of the fundamental structures of the area (Benedek & Douglas 1976, Fig. 7.2). Dr. J. G. Douglas has informed me that the structure shown on the continental shelf in their map was inserted because the geophysical survey showed a change there in the bedrock depth. The submerged cliff was certainly a shoreline in the late Pleistocene, as is shown by the beach deposits. As the sea was rising so rapidly (1-1.5 m per century, according to how low sea level was 18 000 yr BP) an oscillation was necessary to provide the time in which to cut the cliff.

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# B2 POINT ROADKNIGHT TO SUGARLOAF

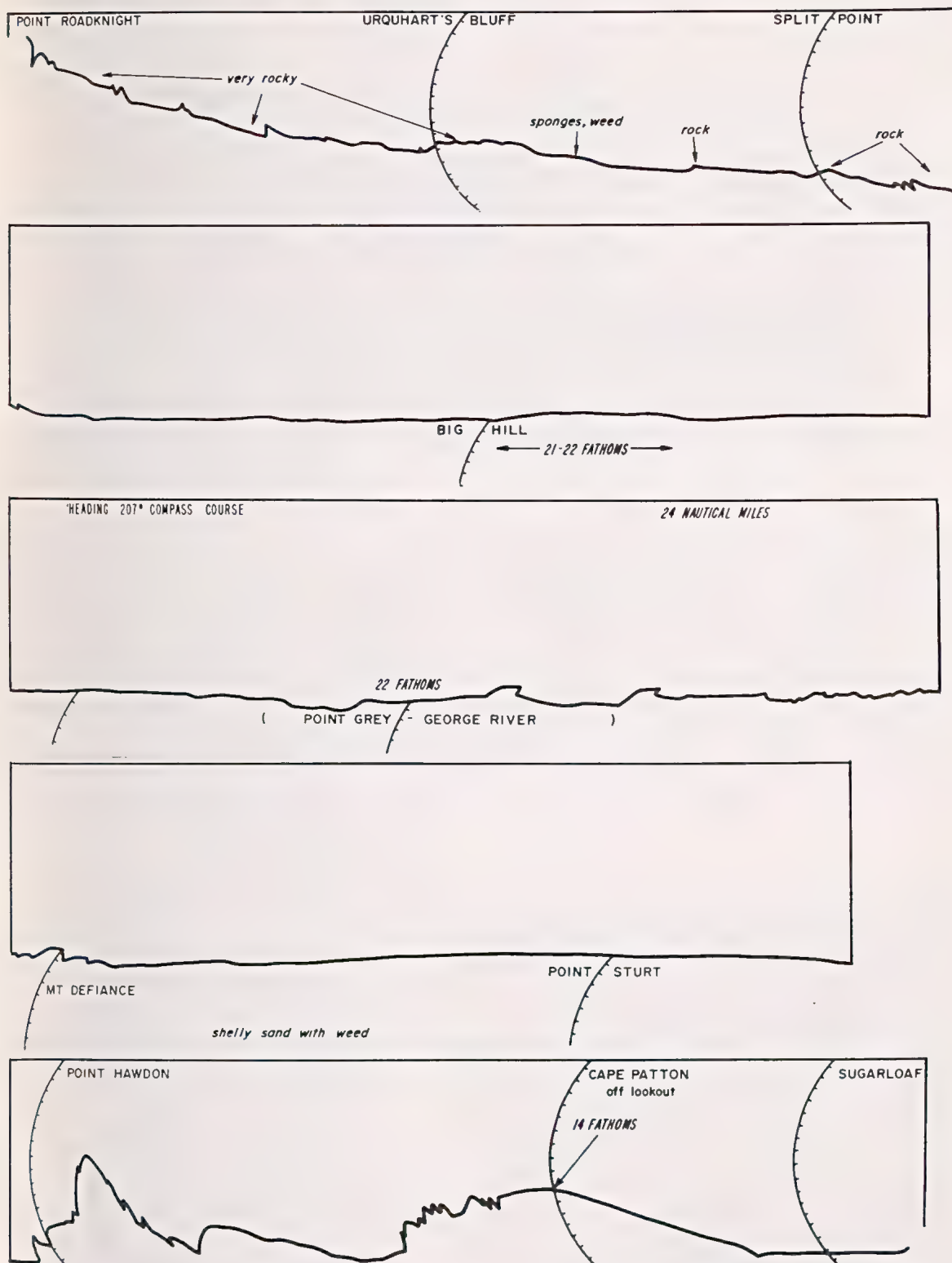


Fig. 4.—Sonar trace B2 parallel to the coast from Point Roadknight near Anglesea to the Sugarloaf southwest of Cape Patton. As the trace covers 24 nautical miles, it has been necessary to cut it into sections for reproduction.





## STUDIES ON AUSTRALIAN MANGROVE ALGAE

## I. Victorian Communities: Composition and Geographic Distribution

By ALLAN DAVEY\* and WM. J. WOELKERLING\*

**ABSTRACT:** This study of the algal communities associated with the temperate mangrove ecosystems of Victoria, Australia, documents the occurrence of 23 species including 6 Chlorophyta, 1 Chrysophyta, 3 Phaeophyta, and 13 Rhodophyta. Pertinent morphosystematic and distribution data are presented for each species. Although the Victorian mangrove algal flora is far more diverse than previously thought, it is exceedingly depauperate and pedestrian when compared with the southern Australian marine algal flora as a whole. Most species found are widely distributed on a global basis. Frequency data indicate that *Caloglossa leprieurii* occurs most commonly but that most species found occur only rarely or sporadically.

## INTRODUCTION

Numerous accounts of mangrove vegetation have appeared since 1950 (see references listed in Chapman 1976, Lugo & Snedaker 1974, and Macnae 1968) and include various Australian based studies (e.g. Ashton 1972, Bird 1971, 1972, Clarke & Hannon 1967, 1969, 1970, 1971, Hutchings & Recher 1974, Macnae 1966, Ministry for Conservation, Victoria 1975, Saenger *et al* 1977). These reports, however, contain comparatively little data on the mangrove algal communities present. Indeed, most studies of mangrove algae have been confined to the tropics (e.g. Almodovar & Pagan 1971, Biebl 1962, Boergesen 1911, Burkholder & Almodovar 1974, Feldmann & Lami 1936, Kuenzler 1974, Post 1936 *et seq*, Taylor 1959, Tseng 1942, 1943).

In temperate regions (i.e. poleward of 30° lat.), mangroves occur only in southern Australia (Table 1) and northern New Zealand in the southern hemisphere, and only in southern Japan and in Bermuda in the northern hemisphere, but again, few algal data are available. Thus Hosokawa *et al* (1977) omit mention of algae in their review of Japanese mangrove ecosystems, while Collins and Hervey (1917) and Taylor and Bematowicz (1969) present only cursory observations on Bermuda's mangrove algae. Similarly, only limited information is available for New Zealand (Chapman 1977, p 14, Chapman & Ronaldson 1958) and for southern Australia (Butler *et al* 1977a, 1977b, Post 1963, 1964a, Saenger *et al* 1977, Womersley & Ed-

monds 1958). No detailed floristic surveys of southern Australian mangrove algae have been undertaken, and virtually no ecological data have been collected.

This account presents results of studies on the algal communities associated with mangrove ecosystems in Victoria, Australia, in terms of composition, frequency of species occurrence and geographic distribution, and includes comparisons of these communities with one another, with the marine algal flora of southern Australia in general, and with mangrove algal communities elsewhere.

## STUDY SITES

In Victoria, mangrove ecosystems are dominated entirely by *Avicennia marina* (Forster) Vierhapper and occur in five distinct regions (Fig. 1; Table 1). The mangroves generally form more or less open canopy scrub communities in which trees rarely exceed 4 m in height (Pl. 7, 1). This contrasts with tropical Australian mangrove ecosystems which generally develop multispecies closed forests with trees up to 30 m tall (Saenger *et al* 1977). The distribution of *Avicennia* in Victoria and southern Australia (Table 1) is probably controlled by winter air temperatures (Chapman 1976); in Melbourne the mean daily minimum temperature for July is 4°C (Macnae 1966). The stands of *Avicennia* (Pl. 7, 2) along the southern shore of Corner Inlet (38°55' S) are the most poleward occurrences of mangroves known (Bird 1972).

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TABLE 1  
LOCATIONS OF THE COOL TEMPERATE AUSTRALIAN MANGROVE ECOSYSTEMS

State	Locality	References
SOUTH AUSTRALIA	1. Ceduna - Streaky Bay Region	2, 4
	2. Gulf of St. Vincent (from Price to Port Adelaide)	2, 3
	3. Spencer Gulf (from Tumby Bay to Wallaroo)	2, 3
VICTORIA	1. Andersons Inlet	1
	2. Barwon Heads	1, 4
	3. Corner Inlet (from Millers Landing to east of Port Welshpool)	1, 4
	4. Port Phillip Bay (Hovells Creek and the Kororoit Creek Estuary)	1, 4
	5. Westernport Bay (from Sandy Pt. to Rhyll, Phillip Island)	1, 3, 4
WESTERN AUSTRALIA	1. Bunbury	3, 4

References: 1. Ashton (1972); 2. Butler *et al.* (1977a); 3. Macnae (1966); 4. Saenger *et al.* (1977).

Westernport Bay affords the most sheltered Victorian mangrove environment and much of the shoreline is fringed intertidally with *Avicennia* stands averaging 40-200 m in width. The trees are mostly 2-3 m tall, extend landward to the high tide mark, and produce numerous pneumatophores which serve as the main substrate for macroscopic algae (Pl. 7, 3). The next most extensive mangrove stands occur in Corner Inlet where most trees are 1-2 m tall and form stands which rarely exceed 40 m in width. In Andersons Inlet a more or less continuous fringe up to 20 m wide occurs with most trees less than 2.5 m tall. Comparatively poor developments of *Avicennia* occur at Barwon Heads and in Port Phillip Bay. At Kororoit Creek (Port Phillip Bay), the mangrove stand includes only one 2.0 m tall tree and 6 smaller trees.

## MATERIALS AND METHODS

Entire *Avicennia* pneumatophores were collected randomly from throughout the mangrove fringe at 16 different localities between March and September 1977. Eight of the 16 study sites were in Westernport Bay, four in Corner Inlet, two in Port Phillip Bay and one each in Andersons Inlet and at Barwon Heads. The pneumatophores were field preserved in 1:10::formalin:seawater and returned to the laboratory for subsequent analyses. Species composition and frequency values were determined for each locality, noting reproductive status and other morphological features of interest for each algal taxon present. Microscopic Cyanophyta and Bacillariophyta have been excluded from this study.

Frequency data are based on observations of 10-40 pneumatophores collected in a random manner from near the seaward margin of each locality; a given frequency value is the ratio of the number of pneumatophores on which a particular alga occurred to

the total number of pneumatophores sampled for frequency analyses at that locality. The relative profusion of taxa has been determined by assigning species to one of the following five categories based on frequency (F) values: *Rare* ( $F < .05$ ); *Sporadic* ( $F = .05-.24$ ); *Occasional* ( $F = .25-.49$ ); *Common* ( $F = .50-.75$ ); *Abundant* ( $F > .75$ ). In the text the word 'prevalent' is used to include both the common and abundant frequency classes. This terminology represents a modification of that suggested by Kershaw (1973, pp. 9-12).

Herbarium vouchers, permanent slides and/or liquid preserved specimens of all species from each locality are deposited in LTB (Index Herbariorum abbreviation; see Holmgren & Keuken 1977, p. 485).

## OBSERVATIONS

### COMMUNITY COMPOSITION AND SPECIES DISTRIBUTION

Twenty-three species of coenocytic or multicellular eucaryotic algae (discussed below alphabetically within each division) occurred in the mangrove stands studied, including six Chlorophyta, one Chrysophyta, three Phaeophyta, and thirteen Rhodophyta. At each given locality from 2-13 species were detected (Table 2), and, with the exceptions of Hovells Creek and Kororoit Creek, red algae predominated in the community composition. Green algae occurred at all localities and red algae were collected from 15 of the 16 sample areas, while brown algae were found only at three study sites, and the Chrysophyte alga *Vaucheria* was encountered only once.

In the following list, data provided for each taxon include selected references of taxonomic or geographic significance, type locality, recorded geographic distribution, and brief notes relating to occurrence in Victorian mangrove ecosystems as well as data of taxonomic and/or morphologic interest.

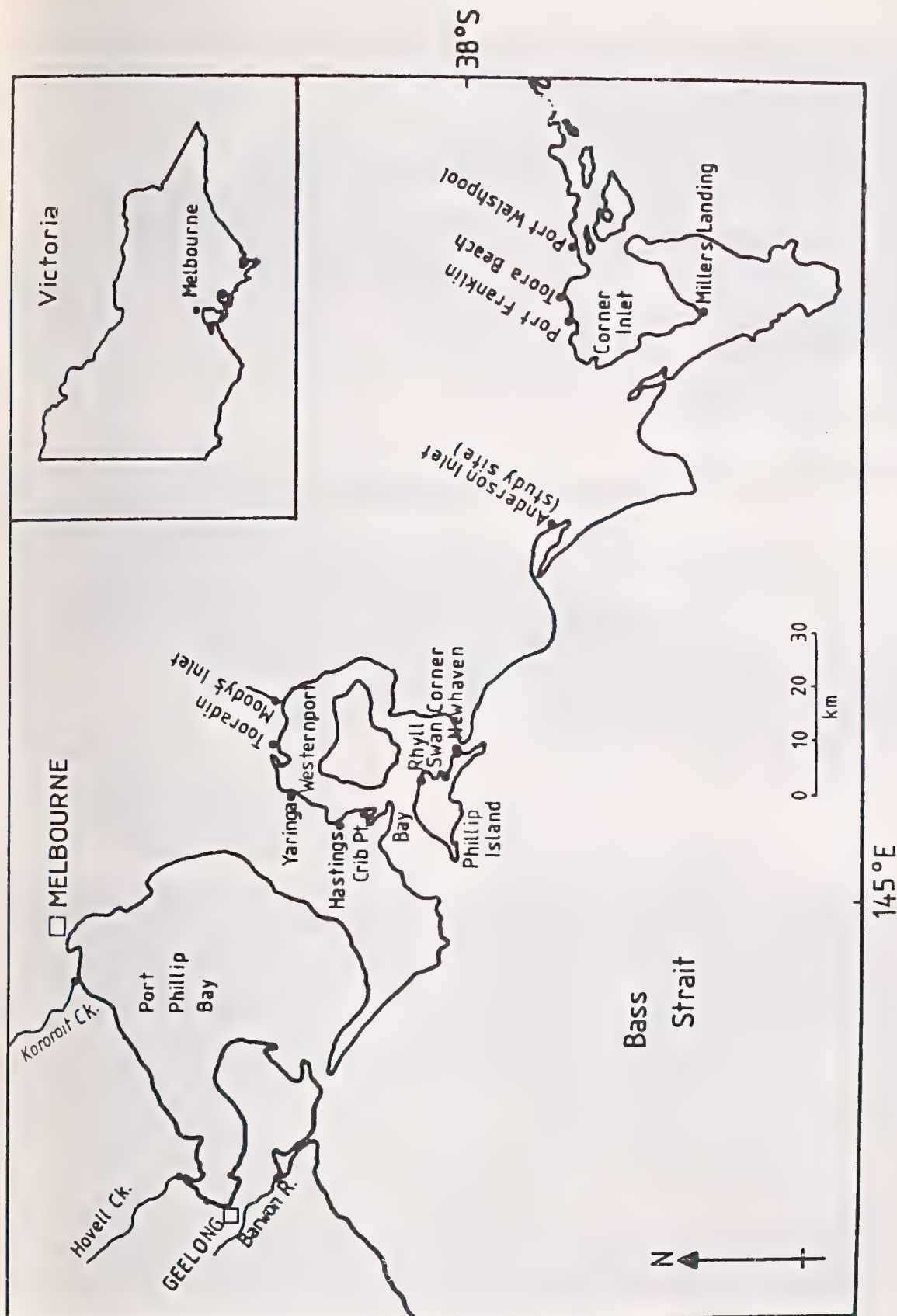


Fig. 1.—The 16 Victorian localities in which sampling was undertaken.





PLATE 7

TABLE 2

SUMMARY OF ALGAL COMMUNITY COMPOSITION DATA FOR VICTORIAN MANGROVE ECOSYSTEMS

Locality	No. of Taxa from Each Division				Total
	Chlorophyta	Chrysophyta	Phaeophyta	Rhodophyta	
Andersons Inlet	3	—	—	5	8
Barwon Heads	1	—	—	3	4
Crib Point	4	1	1	7	13
Hastings	3	—	—	5	8
Hovells Creek	2	—	—	1	3
Kororoit Creek	2	—	—	—	2
Millers Landing	2	—	—	4	6
Moodys Inlet	1	—	—	4	5
Newhaven	1	—	—	6	7
Port Franklin	2	—	—	4	6
Port Welshpool	2	—	2	5	9
Rhyll	2	—	—	6	8
Swan Corner	1	—	—	5	6
Toora Beach	3	—	—	5	8
Tooradin	2	—	—	6	8
Yaringa	2	—	2	9	13

## Division CHLOROPHYTA

Genus *Chaetomorpha* Kuetzing, 1845

*C. capillaris* (Kuetzing) Boergesen 1925:45, Fig. 13. Womersley 1956:356.

TYPE LOCALITY — Nice, south of France.

DISTRIBUTION — Mediterranean and nearby Atlantic Ocean. In Australia, from American River Inlet, Kangaroo Island, and Westernport Bay, Victoria.

SPECIMENS EXAMINED — LTB 10336, 10347, 10358, 10374, 10380, 10387, 10393.

*C. capillaris* occurred at all Westernport localities studied except for Moodys Inlet and usually was encountered sparingly in association with *Bostrychia* and *Caloglossa*.

Genus *Cladophora* Kuetzing, 1843

*Cladophora* sp.

SPECIMENS EXAMINED — LTB 10326, 10350, 10359.

Young plants up to 4 mm tall were found attached to *Avicennia* pneumatophores at Hastings, Millers Landing, and Yaringa. Cells ranged in size from 30-40  $\mu$ m broad and from 130-170  $\mu$ m long, but reliable species identification of these diminutive plants was not possible.

Genus *Enteromorpha* Link., 1820

*E. clathrata* (Roth) Greville 1830: 181. Bliding 1963: 107, Fig. 64-68. Kylin 1949: 28, Fig. 27-29. Womersley 1950: 142; 1956: 352.

TYPE LOCALITY — Europe (see Womersley 1956, p. 352).

DISTRIBUTION — Widespread.

SPECIMENS EXAMINED — LTB 10187, 10193, 10203, 10211, 10219, 10224, 10318, 10327, 10337, 10351, 10374, 10394.

*E. clathrata* was encountered more often than any other green alga and grew at all stations except Hovells Creek, Newhaven, Swan Corner and Yaringa. It predominated the algal flora of pneumatophores at Kororoit Creek, but occurred only as scattered plants elsewhere.

Genus *Percursaria* Bory, 1828

*P. percursa* (C. Agardh) Rosenvinge 1893: 963. Abbott and Hollenberg 1976: 70, Fig. 23. Bliding 1963: 20, Fig. 5-6. Papenfuss 1960: 311, 314. Taylor 1960: 54.

TYPE LOCALITY — Denmark.

DISTRIBUTION — Widespread.

SPECIMEN EXAMINED — LTB 10205.

A population of plants was encountered at Hovells Creek but at none of the other study sites. This species apparently has not been recorded previously from southern Australia (see Womersley 1956, 1971).

Genus *Rhizoclonium* Kuetzing, 1843

*R. riparium* (Roth) Harvey 1851: pl. 239. Cribb 1954: 17, pl. 1, Fig. 9. Taylor 1957: 81, pl. 1, Fig. 3. Womersley 1956: 361.

TYPE LOCALITY — Northern Europe

DISTRIBUTION — Cosmopolitan

SPECIMENS EXAMINED — LTB 10206, 10220, 10319, 10338.

*R. riparium* plants occurred on *Avicennia* at Andersons Inlet and infrequently among *Caloglossa* and/or *Percursaria*.

## EXPLANATION OF PLATE 7

1. The mangrove community at Rhyll showing the open canopy common in Victorian mangrove ecosystems. 2. The most poleward known mangrove community at Millers Landing, Corner Inlet, Victoria. Trees average 2 m in height. 3. *Avicennia* pneumatophores near the seaward fringe at low tide with associated algal communities



*saria* at Hovells Creek. Single specimens also were recorded from Crib Point and Toora Beach pneumatophores.

Genus *Ulva* Linnaeus, 1753

*U. lactuca* Linnaeus 1753: 1163. Bliding 1968: 540, Figs. 3-5. Womersley 1956: 353.

TYPE LOCALITY — Sweden.

DISTRIBUTION — Widespread.

SPECIMENS EXAMINED — LTB 10188, 10194, 10212, 10218, 10320, 10339.

Plants of *U. lactuca* occurred profusely on pneumatophores at Kororoit Creek and also grew conspicuously at stations along the North shore of Corner Inlet and in Andersons Inlet. One plant was found in Westernport Bay (Crib Point).

Division CHRYSOPHYTA

Genus *Vaucheria* deCandolle, 1801

*Vaucheria* sp.

SPECIMEN EXAMINED — LTB 10340.

Plants with several immature oogonia and antheridia and siphons up to 50  $\mu$ m broad were entangled with *Chaetomorpha capillaris* on pneumatophores at Crib Point. Reliable species determination was not possible.

Division PHAEOPHYTA

Genus *Ectocarpus* Lyngbye, 1819

*E. siliculosus* (Dillwyn) Lyngbye 1819:131. Russell 1966:275, Figs. 3-4. Womersley 1967:190.

TYPE LOCALITY — Europe.

DISTRIBUTION — Widespread in temperate and boreal seas.

SPECIMENS EXAMINED — LTB 10341, 10360.

Plants up to 4 mm tall bearing plurilocular sporangia were encountered at the base of pneumatophores at Crib Point and Yaringa.

*Ectocarpus* sp.

SPECIMEN EXAMINED — LTB 10195.

Large sterile tufts of this taxon colonized a pneumatophore at Port Welshpool. Branching was mostly alternate and the main axes were ecorticate. Cells contained several more or less ribbon like chromoplasts and were up to 25  $\mu$ m broad and 40  $\mu$ m long in the main axes. The absence of sporangia precluded accurate species identification.

Genus *Sphacelaria* Lyngbye, 1819

*S. fusca* (Hudson) C. Agardh 1828:34. Sauvageau 1902:206, Fig. 43. Taylor 1960:210. Womersley 1967: 199.

TYPE LOCALITY — Britain.

DISTRIBUTION — Reported from Bermuda, England, Northern France and southern Australia.

SPECIMENS EXAMINED — LTB 10198, 10361.

Several plants were found on pneumatophores at Port Welshpool and Yaringa. The specimens were mostly 3-4 mm tall and bore triradiate non-constricted, linear-armed propagula without central hairs.

Division RHODOPHYTA

Genus *Audouinella* Bory, 1823

*A. microscopia* (Naegeli) Woelkerling 1971:33, Figs. 10, 23A. Woelkerling 1972:85 *et seq.*, Figs. 1-14, 1973a:86; 1973b:557, Figs. 46-51.

TYPE LOCALITY — Bay of Naples, Italy.

DISTRIBUTION — Widespread

SPECIMEN EXAMINED — LTB 10362.

One immature 6-celled plant grew epiphytically on a *Cladophora* plant attached to a pneumatophore at Yaringa.

Genus *Bostrychia* Montagne, 1842

*B. intricata* (Bory) Montagne 1852:317, Kuetzing 1865:9, pl. 23, figs. d-f. Tseng 1943:174, pl. 1, figs. 4-5.

TYPE LOCALITY — Falkland Islands.

DISTRIBUTION — Widespread in subantarctic regions and in warmer waters on littoral zone rocks, muds and mangroves.

SPECIMENS EXAMINED — LTB 10215, 10221B, 10357, 10371, 10379, 10386, 10392.

Plants of *B. intricata* were commonplace on *Avicennia* pneumatophores at Toora Beach and also all Westernport Bay localities except Crib Point and Hastings. All specimens examined were sterile and grew intermixed with other species of *Bostrychia*. Use of the name *B. intricata* rather than *B. mixta* Hooker and Harvey follows Tseng (1943), who regards the latter as a synonym of *B. intricata*. Post (1963, 1964a) records this taxon (as *B. mixta*) from littoral zone mud surfaces on Kangaroo Island, S.A., and at Tidal River, Victoria. Both localities are devoid of mangroves. Saenger *et al* (1977 p. 317) also record this taxon (as *B. mixta*) from mud and *Avicennia* pneumatophores in Queensland.

*B. moritziana* (Sonder in Kuetzing) J. Agardh 1863:862. Post 1936:10; 1963:57; 1964a:244. Taylor 1960:596.

TYPE LOCALITY — French Guiana.

DISTRIBUTION — Widespread in tropical and temperate seas.

SPECIMENS EXAMINED — LTB 10191, 10201, 10207, 10213, 10221A, 10321, 10328, 10334, 10348, 10355, 10369, 10377, 10384, 10390.

*B. moritziana* was encountered at more localities than any other species of *Bostrychia* and occurred everywhere except at the two Port Phillip Bay study sites. Plants often clothed *Avicennia* pneumatophores and in some cases bore cystocarps or tetrasporangia. Male plants were not observed. Specimens from southern Australia examined by Post (1963, 1964a) grew on littoral zone mud flats and rocks as well as on *Avicennia*.

*B. radicans* (Montagne) Montagne 1850:286. Post 1936:13; 1963:53; Taylor 1960:595. Tseng 1943:168, pl. 1, Figs. 1-3.

TYPE LOCALITY — Sinnamary, French Guiana.

DISTRIBUTION — Widely distributed in tropical and temperate waters.

SPECIMENS EXAMINED — LTB 10192, 10202, 10208, 10214, 10322, 10329, 10335, 10349, 10356, 10370, 10378, 10385, 10391.

The Victorian distribution of *B. radicans* and *B. moritziana* appear to be identical except for the absence of *B. radicans* at Moodys Inlet, and the two taxa almost always grew intermixed on pneumatophores. *B. radicans* plants also occurred epiphytically on *Caloglossa* and *Catenella*. Tetrasporic and cystocarpic plants of *B. radicans* were encountered on occasion, but male plants were not observed. Apparently, this taxon has not been reported from southern Australia before, but Saenger *et al* (1977) record it from Queensland.

*B. scorpioides* (Gmelin) Montagne 1842:39. De Toni 1905:1164. Falkenberg 1901:519, pl. 12, figs. 1-2. Kuetzing

1865:7, pl. 18, figs. a-d. Post 1936:34; 1963:78; 1964a:242. Taylor 1960:597.

*B. harveyi* Montagne 1852:317. De Berg 1949:499. De Toni 1905:1163. Garnet 1971:95. Harvey 1860:299; 1863:pl. 292.

TYPE LOCALITY — Great Britain.

DISTRIBUTION — Widely distributed in tropical and temperate waters.

SPECIMEN EXAMINED — LTB 10323.

Sterile plants of *B. scorpioides* grew on *Avicennia* pneumatophores at Andersons Inlet, but were not found elsewhere. Post (1964a) also recorded this species on mud from Tidal River, Leonard Bay and Sealers Cove at Wilsons Promontory. Application of the names *B. scorpioides* and *B. harveyi* to Australian plants requires further clarification including examination of relevant type collections. Post (1936, p. 34) considered *B. harveyi* to be a later synonym of *B. scorpioides*; however, de Berg (1949) argued that the two taxa are distinct, based on studies of New Zealand plants. Nevertheless Post (1963, 1964a) subsequently maintained that *B. harveyi* is identical to *B. scorpioides*, and until the matter can be clarified further from studies of additional Australian collections and comparisons with the types, it seems logical to follow Post, who has examined both Australian and European material. Saenger *et al* (1977, p. 317) also use the name *B. scorpioides*.

#### Genus *Caloglossa* J. Agardh, 1876

*C. lepriurii* (Montagne) J. Agardh 1876: 499. Dawson 1956: 57, Fig. 59. Feldmann & Lami 1936: 883. Papenfuss 1961: 8, Figs. 1-4. Post 1936: 46; 1963: 99; 1964a: 242. Womersley & Bailey 1970: 327.

TYPE LOCALITY — Cayenne, French Guiana.

DISTRIBUTION — Widespread in tropical and temperate waters.

SPECIMENS EXAMINED — LTB 10190, 10200, 10204, 10209, 10216, 10222, 10324, 10330, 10333, 10346, 10354, 10368, 10376, 10383, 10389.

*C. lepriurii* occurred at all localities except Kororoit Creek, thus making it the most widely distributed alga in Victorian mangrove ecosystems. In some cases it was the sole alga present on a given pneumatophore. Tetrasporangial and cystocarpic plants were observed on occasion, but most plants were sterile. King *et al* (1971), Post (1963, 1964a), Saenger *et al* (1977), and Sonder (1855, as *Delesseria*) previously recorded *C. lepriurii* from Victoria.

#### Genus *Catenella* Greville, 1830

*C. nipae* Zanardini 1872: 143, pl. 6A, Figs. 1-7. Min-Thein & Womersley 1976: 50, Figs. 17, 56. Post 1936: 68; 1963: 116, Fig. 8; 1964a: 251. Tseng 1942: 143.

TYPE LOCALITY — Sarawak, Borneo.

DISTRIBUTION — India, Indonesia, eastern and southeastern Australia, New Zealand (see Post 1936, 1963).

SPECIMENS EXAMINED — LTB 10189, 10210, 10217, 10223, 10325, 10331, 10332, 10345, 10353, 10367, 10375, 10382, 10388.

*C. nipae* occurred conspicuously on pneumatophores at all localities in Westernport Bay, Andersons Inlet, and Corner Inlet, but was not found in Port Phillip Bay or at Barwon Heads. Tetrasporic plants were commonplace and

cystocarpic plants infrequent. Often *C. nipae* occurred as the sole alga on a particular pneumatophore.

#### Genus *Centroceras* Kuetzing, 1841

*Centroceras* sp.

SPECIMEN EXAMINED — LTB 10342.

A solitary sterile plant 6 mm tall occurred at the base of a pneumatophore at Crib Point. The filaments were up to 100  $\mu$ m broad and successive nodes were separated by 11-12 cells, but reliable species identification was not possible.

#### Genus *Ceramium* Roth 1797

*Ceramium macilentum* J. Agardh 1894: 15. Womersley 1978: 232.

TYPE LOCALITY — Port Phillip Bay, Victoria.

TYPE — LD.

DISTRIBUTION — see Womersley 1978.

SPECIMEN EXAMINED — LTB 10343.

A single sterile tuft of filaments was encountered on one Crib Point pneumatophore.

#### Genus *Chondria* C. Agardh, 1817

*Chondria* sp.

SPECIMEN EXAMINED — LTB 10352.

Several tetrasporangial plants 4-5 cm tall colonized the lower half of a pneumatophore at Hastings. The tetrasporangial branches were markedly flattened and the sporangia averaged 40  $\mu$ m in diameter.

#### Genus *Colaconema* Batters, 1896

*C. humilis* (Rosenvinge) Woelkerling 1971: 44, Figs. 15 J-O; 1937b: 529, Figs. 66-73.

TYPE LOCALITY — Spodobjerg, Langeland, Denmark.

DISTRIBUTION — Atlantic and Mediterranean shores of Europe, northeastern United States, southeastern Australia.

SPECIMEN EXAMINED — LTB 10363.

Plants occurred on an unidentified red alga epiphytic on a pneumatophore at Yaringa.

#### Genus *Diplocladia* Kylin, 1956

*D. patersonis* (Sonder) Kylin 1956: 504.

TYPE LOCALITY — Cape Paterson, Victoria.

DISTRIBUTION — S. Australia, Tasmania, Victoria.

SPECIMENS EXAMINED — LTB 10196, 10364.

Sterile plants up to 1.5 cm tall, colonized pneumatophores at Yaringa and Port Welshpool.

#### Genus *Polysiphonia* Greville, 1824

*Polysiphonia* sp.

SPECIMENS EXAMINED — LTB 10344, 10365, 10374, 10381, 10395.

Single tetrasporangial plants grew on pneumatophores at Crib Point, Newhaven, Rhyll, Tooradin and Yaringa. In all cases the plants were ecorticate with four pericentral cells, but reliable specific identification could not be made.

## FREQUENCY DATA

Based on frequency data (Table 3), seven taxa (*Audouinella microscopica*, *Centroceras* sp., *Ceramium macilentum*, *Chondria* sp., *Colaconema humilis*, *Sphacelaria fusca*, *Vaucheria* sp.) of the total



TABLE 3  
FREQUENCY OF SPECIES OCCURRENCE FROM THE 16 LOCALITIES STUDIED IN VICTORIA

Locality	Andersons Inlet	Barwon Heads	Crib Pt.	Hastings	Hovells Creek	Kororoit Creek	Millers Landing	Moody's Inlet	Newhaven
No. of pneumatophores Taxon sampled	40	39	25	26	39	16	30	10	22
CHLOROPHYTA									
<i>Chaetomorpha capillaris</i>			.32	.23					.23
<i>Cladophora</i> sp.				.03			.07		
<i>Enteromorpha clathrata</i>	.03	.26	.04	.03		1.0	.07	.50	
<i>Percursaria percursea</i>					.23				
<i>Rhizoclonium riparium</i>	.55		.04		.23				
<i>Ulva lactuca</i>	.05		.04			1.0			
CHRYSTOPHYTA									
<i>Vaucheria</i> sp.			.04						
PHAEOPHYTA									
<i>Ectocarpus siliculosus</i>			.04						
<i>Ectocarpus</i> sp.									
<i>Sphacelaria fusca</i>									
RHODOPHYTA									
<i>Audouinella microscopica</i>									
<i>Bostrychia intricata</i>								.90	.27
<i>B. moritziana</i>	.05	.26	.68	.73			.80	.40	.50
<i>B. radicans</i>	.40	.46	.60	.73			.54		.77
<i>B. scorpioides</i>	.25								
<i>Caloglossa leprieurii</i>	.43	1.0	.96	.96	1.0		.80	.30	.55
<i>Catenella nipae</i>	.68		.64	.53			.30	.30	.64
<i>Centroceras</i> sp.			.04						
<i>Ceramium</i> sp.			.04						
<i>Chondria</i> sp.				.03					
<i>Colaconema humilis</i>									
<i>Diplocladia patersonis</i>									
<i>Polysiphonia</i> sp.			.04						.05

TABLE 3 (Continued)

Locality	Port Franklin	Port Welsbpool	Rhyll	Swan Corner	Toora Beach	Tooradin	Yaringa	
No. of pneumatophores sampled								
Taxon	24	40	21	23	40	24	25	F
CHLOROPHYTA								
<i>Chaetomorpha capillaris</i>			.19	.17		.29	.36	.26
<i>Cladophora</i> sp.							.04	.05
<i>Enteromorpha clathrata</i>	.29	.38	.09		.18	.04		.24
<i>Percursaria percursa</i>								.23
<i>Rhizoclonium riparium</i>					.03			.21
<i>Ulva lactuca</i>	.08	.10			.10			.23
CHRYSTOPHYTA								
<i>Vaucheria</i> sp.								.04
PHAEOPHYTA								
<i>Ectocarpus siliculosus</i>							.08	.06
<i>Ectocarpus</i> sp.		.05						.05
<i>Sphacelaria fusca</i>		.03					.04	.04
RHODOPHYTA								
<i>Audouinella microscopica</i>							.04	.04
<i>Bostrychia intricata</i>			.19	.69	.15	.17	.08	.35
<i>B. moritziana</i>	.38	.40	.72	.50	.50	.75	.68	.53
<i>B. radicans</i>	.29	.33	.67	.53	.53	.75	.68	.56
<i>B. scorpioides</i>								.25
<i>Caloglossa leprieurii</i>	.54	.75	.48	.60	.60	.83	.56	.69
<i>Catenella nipae</i>	.67	.48	.38	.53	.53	.79	.64	.55
<i>Centroceras</i> sp.								.04
<i>Ceramium macilentum</i>								.04
<i>Chondria</i> sp.								.03
<i>Colaenema humilis</i>							.04	.04
<i>Diplocladia patersonis</i>		.08					.04	.06
<i>Polysiphonia</i> sp.			.05			.04	.04	.04



of 23 recorded must be considered rare ( $F < .05$  for all localities) and an additional six (*Cladophora* sp., *Diplocladia patersonis*, *Ectocarpus siliculosus*, *Ectocarpus* sp., *Percursaria percurta*, *Polysiphonia* sp.) classed as rare ( $F < .05$ ) or sporadic ( $F = .05-.24$ ) depending on the locality. This includes two of the six species of Chlorophyta, all of the Chrysophyta and Phaeophyta and seven of the 13 Rhodophyta. All of these species appear to be relatively inconsequential in Victorian mangrove ecosystems.

Of the remaining 10 taxa, four (*Bostrychia moritziana*, *B. radicans*, *Caloglossa leprieurii*, and *Catenella nipae*) were common ( $F = .50-.75$ ) or abundant ( $F > .75$ ) at most localities of occurrence, and six (*Bostrychia intricata*, *B. scorpioides*, *Chaetomorpha capillaris*, *Enteromorpha clathrata*, *Rhizoclonium riparium*, *Ulva lactuca*) showed marked variations in frequency values and could be considered rare to abundant depending upon locality. Based on mean frequency values [i.e.  $\sum F/N$ , where  $\sum F$  is the sum of all recorded frequencies  $> 0$  and 'N' is the total number of localities at which the alga occurred; (see Table 3)], *Caloglossa leprieurii* is the most conspicuous alga in the Victorian mangrove ecosystems.

At any given locality (Table 3) from 1-5 species of algae were common ( $F = .50-.75$ ) or abundant ( $F > .75$ ). In two instances (Andersons Inlet, Moodys Inlet) one of the prevalent species ( $F = .50-1.0$ ) was a green alga, and in one other instance (Kororoit Creek), both prevalent species were green algae. For the remaining

13 localities, common or abundant frequency values occurred only among red algae.

At half the study sites, only one or two species had frequency values of .50 or greater; at the other study sites, from three to five species occurred with frequency values of .50 or more. No clear relationship, however, seems to exist between the number of prevalent species and the total number of species present at a locality (Table 4).

## DISCUSSION

The algal flora of Victoria's mangrove ecosystems is exceedingly depauperate and pedestrian when compared with the southern Australian marine algal flora as a whole. Based on published species estimates (Womersley 1959), only six of the 98 Chlorophyta, three of the 191 Phaeophyta, and thirteen of the 725 Rhodophyta species known to occur in southern Australian seas were encountered in Victorian mangrove ecosystems. (Data on the Chrysophyta are too meagre to make meaningful comparisons). This represents percentage occurrences of 6.1, 1.6, and 1.8 respectively. Furthermore, only two (*Ceramium macilentum*; *Diplocladia patersonis*) of the 23 taxa found are endemic to southern Australia; the remaining taxa all have been recorded outside Australian waters, and most are widespread. Two species (*Bostrychia radicans*, *Percursaria percurta*), however, apparently have not been reported from southern Australia previously. All 23 species are known to occur outside of mangrove environments, but six species encountered in this study (*Audouinella microscopica*, *Colaconema humilis*, *Diplocladia patersonis*, *Ectocarpus siliculosus*, *Percursaria percurta*, *Sphacelaria fusca*) apparently have not been reported previously from mangrove ecosystems.

Of the 16 localities examined, four (Barwon Heads, Hovells Creek, Kororoit Creek, Moodys Inlet) were estuarine in nature, while 12 were not subject to the influence of fresh or brackish water. The total flora at these four localities was less diverse (2-5 taxa) than that of the more marine sites (6-13 taxa), and only one species (*Percursaria percurta*) appeared to be confined to these estuarine environments. In contrast, 14 species occurred only in the marine environments (Table 3). The four ecologically most significant algae (based on frequency values, see Table 3) all occurred at every marine locality sampled; however, none occurred at Kororoit Creek. In addition, *Bostrychia radicans* did not occur at Moodys Inlet, and *Catenella nipae* was not found at Barwon Heads. Thus, estuarine influence appears to affect adversely algal diversity within the mangrove ecosystems investigated.

Results from this study also suggest that the Victorian mangrove algal flora (i.e. Chlorophyta,

TABLE 4

RELATIONSHIPS BETWEEN THE NUMBER OF PREVALENT ALGAL SPECIES ( $F = .50-1.0$ ) AND THE TOTAL NUMBER OF ALGAL SPECIES IN VICTORIAN MANGROVE ECOSYSTEMS

Locality	# Prevalent Species	$P_s/T_s^1$
Barwon Heads	1	.25
Hovells Creek	1	.33
Port Welshpool	1	.11
Andersons Inlet	2	.25
Kororoit Creek	2	1.00
Moodys Inlet	2	.40
Port Franklin	2	.33
Rhyll	2	.25
Millers Landing	3	.50
Crib Point	4	.31
Hastings	4	.50
Newhaven	4	.57
Toora Beach	4	.50
Tooradin	4	.50
Yaringa	4	.31
Swan Corner	5	.83

<sup>1</sup> $P_s$  = Number of prevalent species;  
 $T_s$  = Total number of species.

TABLE 5

COMPARISONS OF ALGAL FLORAS RECORDED FROM VARIOUS AUSTRALIAN MANGROVE ECOSYSTEMS  
BASED ON DATA FROM SAENGER *et al.* 1977 AND THIS STUDY

Taxon	Victoria (Present Study)	Victoria (Saenger <i>et al.</i> )	N.S.W.	Qld.	Australia (Saenger <i>et al.</i> and This Study)
Chlorophyta	6	—	—	5	7
Chrysophyta	1	—	—	—	1
Phaeophyta	3	—	—	1	4
Rhodophyta	13	3	4	17	24
Total	23	3	4	23	36
<i>Bostrychia</i>	4	2	3	7	7
<i>Caloglossa</i>	1	1	—	3	3
<i>Catenella</i>	1	—	1	1	1
Total	6	3	4	11	11

Phaeophyta, Rhodophyta) is far more diverse than previously realized and that its species richness may be comparable to that of Queensland mangrove ecosystems (Table 5). Thus 20 (87%) of the 23 species found during this study were not recorded previously from Victorian mangroves, and the species total for Victoria is now identical with that reported (Saenger *et al.* 1977) for tropical Queensland. Species composition in the two areas differs substantially, however, and none of the Chrysophyta or Phaeophyta are common to both regions. Four of the seven Chlorophyta and six of the 24 Rhodophyta occur in both regions, and in the total floras, less than one-third (28%) of the algal species are reported from both tropical Queensland and temperate Victorian mangrove environments. Comparisons of species distribution of *Bostrychia*, *Caloglossa* and *Catenella* indicate that all species of these genera found on Victorian mangroves are also recorded from Queensland mangroves, and reveal also that 2 additional species of *Caloglossa* and 3 of *Bostrychia* occur (based on published records) only on Queensland mangroves. Such comparisons must be viewed with caution, however, since the Queensland data are based solely upon investigations of *Avicennia* pneumatophores, and studies of the algal flora associated with other Queensland mangrove species may produce data which will markedly alter statements made here. The absence of data precludes comparisons of the Victorian and Queensland mangrove algal floras with those of the Northern Territory, South Australia and Western Australia. Likewise data from New South Wales are too meagre (Table 5) to permit meaningful comparative discussions.

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## THE OBERON BAY METEORITE

By M. J. FITZGERALD\*

**ABSTRACT:** The Oberon Bay meteorite which was found on Wilsons Promontory in the early 1960's is described and an analysis presented. In the light of its composition and petrography the meteorite is classified as an LL6 chondrite.

### INTRODUCTION

The Oberon Bay meteorite was found during a Christmas vacation period in the early 1960's; probably 1962-1963. The finder, Dr. V. A. Gostin, was walking through the sandhills near Oberon Bay on Wilsons Promontory when he came upon a sandblow among the dunes. The 180g meteorite was lying on the floor of the blow along with pieces of driftwood, rock fragments and general debris. Dr. Gostin picked it up, as it seemed unusual, and after sectioning it, suspected that it was a meteorite. He retained the specimen until 1972, when his identification was confirmed. He then donated the specimen to the University of Adelaide.

The meteorite has been tentatively identified as an LL chondrite (Hutchinson *et al.* 1977) and the aim of this note is to present a description and analysis of the meteorite and confirm this classification.

### EXPERIMENTAL METHODS

X-ray fluorescence analysis was used for the determination of all elements except sodium for which a flame photometric method was employed. A modified version of the Norrish and Hutton (1969) technique for X.R.F. analysis was used. Olivine determinations were carried out both by an X-ray diffraction method using the technique of Yoder and Sahama (1957) involving the measurement of  $d_{130}$  spacings with zinc oxide as the internal standard and by electron microprobe. In the latter instance a Technisch Physiche Dienst microprobe fitted with a lithium drifted silicon detector was used and the data reduced using the method of Reed and Ware (1975). Full details of all methods are given in Fitzgerald (1979a.).

### DESCRIPTION OF THE METEORITE

The shape of the meteorite is an oblate spheroid with a diameter of about 5 cm (Pl. 8). Prior to its

discovery it had fractured in at least two places. These are now outlined on the relatively fresh surface by a 1-2 mm ridge of well rounded grains of quartz and other terrestrial detritus, of about 0.2 mm diameter, cemented together in a limonitic matrix. In places this 'conglomeratic crust' coats the meteorite over an area of many square millimetres and as it is very similar to the meteorite and does not readily separate from it, is not at first obvious. Because of this extra care was taken in preparing a sample for analysis. Separation along two of the fractures revealed a limonitic layer coating the joint surface. Several chondrules are visible penetrating the fusion crust. The overall spherical shape of the specimen is not interrupted by any feature indicative of flight orientation or resulting from ablationary sculpturing.

Numerous metal and sulfide grains, a few of which are surrounded by limonitic staining, can be seen on a cut surface. Areas of apparent complete replacement of metal or sulfide by limonite are also visible. Chondrules and rounded inclusions can be seen on this surface. The silicates vary from white through yellow to grey while the abundant disseminated sulfides give the matrix an overall black colour.

The grain size of the silicates is very variable. Although large, subrounded, fragments of silicate material are present, very few definite chondrules can be seen in thin section (Pl. 8, below). Some of the clasts consist of fragments of recognizable chondrule types, commonly partly rimmed by finer chondritic matrix but others consist solely of previously fragmented fine chondrule debris. Some of the coarser clasts have a granoblastic texture with numerous triple point junctions but others are composed of large fragments of very fine grained material set in a fine matrix. These appear to be remnants of porphyritic material in which the megacrysts and glassy mesostasis have been completely recrystallized. By contrast other porphyri-

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## PLATE 8

(Above) Exterior view of Oberon Bay meteorite showing fractures outlined by limonite-cemented quartz grains (Scale bar 1 cm).

(Below) Thin section showing the fragmental nature of the Oberon Bay chondrite (Scale bar 5 mm).

tic clasts show minimal devitrification and recrystallization. Several of the clasts bear a superficial resemblance to C2 meteorites such as Adelaide (Fitzgerald & Jones 1977). The matrix content of the clasts is less than that of these carbonaceous chondrites however. Many of the clasts have sharp boundaries but others grade into the matrix which consists of very fine silicates set in an opaque base. Nickel-iron is generally far more abundant in this dark material and troilite is ubiquitous.

Many of the larger silicate grains exhibit varying degrees of shock in the form of undulose extinction and mosaic textures. Commonly the large orthopyroxene grains poikilitically enclose olivine chadacrysts and in some cases the grains are almost completely poikilitic with triple point boundaries between the olivine chadacrysts. Occasional grains of polysynthetically twinned clinopyroxene are also present.

### BULK CHEMICAL COMPOSITION

The bulk composition is listed in Table 1 along with the results of a normative mineral calculation. The assumptions made in this modified form of the CIPW calculation are fully documented in Fitzgerald (1979a). Phosphorus is assigned to the mineral merrillite ( $\beta$ - $\text{Co}_2(\text{PO}_4)_2$ ) as Dowty (1977) has shown this is the principal meteoritic phosphate species.

### CLASSIFICATION

Values of the atomic ratios (expressed on a percentage basis) Ca/Mg (5.3), Fe/(Fe+Mg) (35), Al/Si (6.3) and Ca/Si (4.7) all lie within the limits used by Fitzgerald (1979a) to define the ordinary chondrites. Both the total iron content (18.4%) and the low value of 49 for the Fe/Si ratio are suggestive of an LL chondrite classification. The olivine composition as measured by X-ray diffraction is  $\text{Fa}_{25.5}$  whereas the electron microprobe revealed the presence of a bimodal population of olivine grains, one having a mean composition of  $\text{Fa}_{25.6}$  and the other  $\text{Fa}_{17.7}$ . A Coefficient of Variation of 0% for the first group showed this olivine to be homogeneous and well equilibrated whereas the value of 6% for the second group was indicative of a lack of equilibration. That the abundance of this second group of olivine grains is low is shown by the identity of the more iron-rich probe determinations and the diffraction results, the latter technique effectively measuring the average olivine composition. This olivine composition falls close to the accepted boundary between the L and LL chondrite groups and so could be interpreted as indicating either classification. The more iron-rich olivine occurs throughout the meteorite whereas the iron-poor variety

is confined to the finer grained clasts which texturally resemble the carbonaceous chondrites mentioned above. The mean orthopyroxene composition of  $\text{Fs}_{22.5} \text{Wo}_{1.5}$ , as determined by the microprobe, is consistent with either classification. Unlike the olivine, two groups of pyroxene compositions were not detected, but a C.V. of 3% indicates the range of measured values.

Several authors (e.g. Mason & Wiik 1964 and Fodor & Keil 1975a) have suggested that the LL chondrites are characterized by a scarcity of chondrules and a prominent brecciation. Fodor and Keil also described poikilitic fragments from five LL chondrites, generally finding olivine chadacrysts poikilitically enclosed in orthopyroxene oikocrysts. Wasson (1974) suggested that the LL chondrites are generally genomict breccias, that is, breccias consisting of material from the same chemical group but with different histories. He used this terminology to distinguish the LL chondrites from Wahl's (1952) polymict breccias in which the clasts are not necessarily related to the interstitial host or matrix. Wasson further suggested that the host and xenolith material of all the brecciated ordinary chondrites invariably belonged to the same chemical group, but recent work has shown that this is not always the case (e.g. Fodor & Keil 1975a,b, Fodor & Keil 1976, Fodor *et al* 1976). It appears that there are several true polymict brecciated chondrites in which the included clasts have bulk compositions significantly different from that of the host. Fodor and Keil (1975a) examined the LL3 chondrite Ngawi and concluded that even though it has an LL bulk composition it contains fragments having compositions corresponding to H, L and LL material. Plainview (1917) as described by Fodor and Keil (1976) consists of quite large light coloured fragments set in a dark matrix, and in addition, exotic lithic fragments are found in the dark matrix. A similar situation obtains in the case of Oberon Bay where the exotic lithic fragments appear to be confined to the fine matrix. However the situation is not as simple as in the case of Plainview, since some of the exotic clasts in Oberon Bay are of the same size, or larger, than the ordinary light coloured fragments.

Fodor and Keil (1975a) suggested that the poikilitic textures of the LL chondrites were produced during slow cooling following impact events. The brecciated and shocked nature of Oberon Bay attests to the role of impact events in its formation. It is also possible that the exotic fragments present in the meteorite are remnants of some of the projectiles which impacted the surface of the Oberon Bay parent body and further work on these clasts is planned.

In addition to the analytical results for Oberon Bay, Table 1 contains data for three other LL chondrites — Ngawi (LL3), Mossiel (LL4) and Lake



TABLE 1  
BULK CHEMICAL COMPOSITIONS AND NORMATIVE MINERALOGIES

	Oberon Bay <sup>1</sup>	Ngawi <sup>2,4</sup>	Mossgiel <sup>3</sup>	Lake Labyrinth <sup>3</sup>
Elemental abundances (weight percent) •				
Fe	18.43	19.03	18.38	19.70
Mn	0.28	0.26	0.26	0.31
Ti	0.081	0.064	0.088	0.073
Ca	1.30	1.33	1.14	1.41
K	0.126	0.077	0.050	0.103
P	0.084	0.079	0.061	0.157
Si	19.23	18.88	18.83	19.37
Al	1.17	1.17	1.27	1.42
Mg	15.00	15.34	15.44	16.03
Ni	1.28	1.06	1.15	1.20
S	2.15	2.22	1.93	2.00
Cr	0.31	0.42	0.29	0.31
Na	0.71	0.73	0.55	0.86
Atomic ratios (percentages)				
Ca/Mg	5.3	5.3	4.5	5.3
Fe/(Fe+Mg)	35	35	34	35
Al/Si	6.3	6.5	7.0	7.6
Ca/Si	4.7	4.9	4.3	5.1
Fe/Si	49	51	49	51
Normative mineralogy (weight percent)				
Nickel-iron	10.5	8.6	9.4	9.3
Troilite	6.2	6.3	5.5	5.5
Merrillite	0.4	0.4	0.3	0.8
Ilmenite	0.3	0.2	0.3	0.2
Chromite	0.7	0.9	0.7	0.7
Feldspar	10.7	10.5	10.1	12.2
Diopside	5.5	6.2	3.4	4.7
Orthopyroxene	38.4	30.4	37.2	25.4
Olivine	27.4	36.6	33.1	41.2
Normative molar percent composition				
Ab } Feldspar	80	82	66	81
An }	12	13	31	13
Fs Pyroxene	13	16	15	16
Fa Olivine	16	19	18	19

## References:

1. This work

2. Ahrens et al. (1969)

3. Fitzgerald (1979b)

4. Mason and Wiik (1966)

Labyrinth (LL6). The brecciated nature of Oberon Bay obviously affects its bulk composition as this will simply be the average of the clasts and matrix which have been sampled and thus the marked resemblance between Oberon Bay and the other meteorites listed in Table 1 is significant.

Accordingly, on the basis of mineral and bulk compositions and textural features, Oberon Bay is classified as an LL chondrite. Despite the presence of occasional grains of polysynthetically twinned clinopyroxene, the absence of well developed feldspar, and the prominent nature of the clasts in this meteorite, the overall degree of recrystallization within the clasts is appropriate to petrologic type 6. Oberon Bay is accordingly classified as an LL6 chondrite and is thus another example of a polymict chondritic breccia.

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## THE DISTRIBUTION OF *Callianassa* SPECIES (CRUSTACEA, DECAPODA) IN WESTERN PORT, VICTORIA

By NOEL COLEMAN\* AND GARY C. B. POORE\*\*

**ABSTRACT:** A recent survey has shown three species of the shrimp genus *Callianassa* to be widespread in Western Port, Victoria. *C. arenosa* Poore and *C. australiensis* (Dana) occur mainly in intertidal and shallow (<10 m) subtidal areas while the range of *C. limosa* Poore extends into deeper (>10 m) areas. *C. arenosa* and *C. limosa* were found in muddier sediments than those in which *C. australiensis* was taken. The presence of vegetation and shell debris in sediments reduced population densities and the frequency of occurrence of all species.

The relationships between the distribution of *Callianassa* and sediment type in Western Port are compared with those reported for these species in other areas.

### INTRODUCTION

Port Phillip Bay and Western Port, two adjacent Victorian bays, have in common several species of the shrimp genus *Callianassa*. The distribution and sediment relationships of the species in Port Phillip Bay have already been described (Poore 1975). Detailed information for the species in Western Port is not available but recent benthic surveys (Coleman *et al.* 1978, Coleman unpublished) suggest that the environmental relationships of *Callianassa* there may differ from those in Port Phillip. This paper reports on an investigation of the abundance, distribution and sediment preferences of the three most abundant species of *Callianassa* in Western Port.

### SURVEY AREA

Western Port (Fig. 1) is a marine embayment about 60 km southeast of Melbourne. The bay has a total area of approximately 1450 km<sup>2</sup> but, because of the presence of French and Phillip Islands, the water surface area is only 680 km<sup>2</sup> of which about 40% (270 km<sup>2</sup>) is intertidal. The bay has two deep water channels, North and East Arms, which partially surround French Island. The sediment in these channels is mainly medium to coarse sand. North of French Island are extensive tidal flats which drain through permanent drainage channels into North and East Arms. The sediment of these flats varies from fine sand to silt and clay. Vegetation, mainly seagrass, is found abundantly along the edges of the drainage channels and more sparsely on the rest of the tidal flats. Fine sedi-

ment with varying amounts of vegetation is found in other intertidal and shallow areas, along the edges of North and East Arms, on the spits in North Arm, and in the East Arm Embayment Plain (Ministry for Conservation 1975).

### METHODS

A map of Western Port was divided into nine strata based on sediment type (Shepard classification, Ministry for Conservation 1975: Fig. 4.1.4(b)).

Ninety-seven stations were randomly allocated to these strata (Fig. 1), each stratum receiving a number of stations proportional to its area. Fifty-two stations were allocated to sand, 5 to silty-sand, 11 to clayey-sand, 1 to silt, 7 to clayey-silt, 17 to clay, 2 to sandy-clay, 1 to silty-clay and 1 to sand-silt-clay.

Stations in East Arm were sampled in April 1977 and stations in North Arm and to the north of French Island in October 1977. At each station, depth, vegetation cover and the nature of the substratum were noted. Sediment to a depth of about 40 cm was removed by divers from three 0.1 m<sup>2</sup> quadrats and sieved, on board a boat, through a 2 mm mesh. Live *Callianassa* were removed from the mesh and frozen.

The specimens were identified in the laboratory. Mean densities of each species were calculated for each of the nine original strata, for the three sandy strata (i.e. sand, silty-sand, clayey-sand) combined, for the six muddy strata combined, for three strata based on depth range (intertidal—3 m; 3–10 m; >10 m), and for twelve strata based on the field obser-

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Fig. 1—Distribution of sediment types and *Callianassa* sampling stations (●) in Western Port. EA, East Arm; EAE, East Arm Embayment Plain; NA, North Arm; TTF, Tooradin Tidal Flats; TD, Tidal Divide.

variations of the amount of vegetation and shell debris present.

## RESULTS

Three species of *Callianassa* were found: *C. arenosa* Poore, *C. australiensis* (Dana) and *C. limosa* Poore. Because the distribution of individuals among samples was positively skewed and because the stations were sampled during two seasons, the differences between strata were not tested statistically. In the following discussion only marked differences are assumed to reflect actual environmental preferences shown by the species.

*Callianassa arenosa* was the most abundant and most frequently collected species and was represented by 393 individuals from 38 stations (Fig. 2). The species was collected throughout the bay, al-

though it was most abundant in the tidal divide region and the East Arm Embayment Plain. No individuals were found below 10 m depth but densities were similar in the two shallower strata (Table 1). *C. arenosa* was found at similar densities on sandy and muddy sediments (Table 1). Vegetation had little effect on population density but there was a tendency for *C. arenosa* to occur in fewer samples from areas with the greatest seagrass cover (Table 2). An increase in shell content of the substratum was associated with decreases in both population density and frequency of occurrence.

*Callianassa australiensis* was the second most abundant but the least frequently encountered species, 256 individuals at only nine stations (Fig. 3). *C. australiensis* co-occurred with *C. arenosa* at four stations and with *C. limosa* at one station but was more restricted than the other species in its sediment associa-



Fig. 2—Distribution of *Callianassa arenosa* in Western Port. Dots indicate survey stations at which *C. arenosa* was found. The dotted line indicates the 5.5 m depth contour.

tions, being found only in sand (Table 1). Its distribution was patchy but it was most abundant in North Arm; no specimens were collected from the Tooradin tidal flats or from the East Arm Embayment Plain. *C. australiensis* preferred shallower areas (Table 1) and was most abundant between 3 and 10 m. In general,

TABLE 1

MEAN DENSITIES (NUMBER PER SQUARE METRE) OF THREE SPECIES OF *Callianassa* ON DIFFERENT SEDIMENT TYPES AND AT DIFFERENT DEPTHS IN WESTERN PORT.

	Sandy	Muddy	<3 m	3-10 m	>10 m
<i>Callianassa arenosa</i>	12.8	13.0	17.4	12.6	0.0
<i>C. australiensis</i>	12.3	0.0	6.5	16.1	0.2
<i>C. limosa</i>	9.0	4.8	4.5	11.4	10.0
Number of Stations	68	29	50	32	15

stations with greatest vegetation cover or shell content had lowest population densities but one shelly, seagrass-covered station was exceptional in having a particularly high number of shrimps (Table 2).

*Callianassa limosa* was the least abundantly collected species (220 individuals) but was widely distributed in the eastern part of the bay (Fig. 4). It was found also at one station at the southern end of North Arm. Unlike the other two species, *C. limosa* was well represented at the deeper stations and showed no preference for sandy or muddy sediments (Table 1). Increase in vegetation cover was associated with decrease in population density and frequency of occurrence of *C. limosa* although, as with *C. australiensis*, this general trend is obscured by one exceptional station. In the absence of vegetation, increase in sediment debris was associated with increases in population density and frequency of occurrence, but these effects were reduced where vegetation cover was greater.



TABLE 2

DENSITIES OF *Callianassa* SPECIES (NUMBERS PER SQUARE METRE) AND PERCENTAGE OF STATIONS AT WHICH EACH SPECIES OCCURRED (IN BRACKETS) IN TWELVE STRATA. STRATA ARE DEFINED ON THE AMOUNT OF SEAGRASS OR ALGAL COVER AND AMOUNT OF SHELL DEBRIS IN THE SEDIMENT. A DASH INDICATES ABSENCE.

Shell Content	Seagrass or Algal Cover				Total
	None	Low	Moderate	High	
<i>Callianassa arenosa</i>					
Low	19.7(45)	28.0(78)	18.7(60)	22.7(33)	22.0(52)
Moderate	9.0(60)	10.0(50)	10.0(50)	—	8.0(46)
High	4.7(24)	1.0(29)	—	8.3(16)	5.0(21)
Total	12.1(38)	15.1(56)	12.7(44)	12.0(20)	13.4(39)
<i>C. australiensis</i>					
Low	15.3(18)	40.3(33)	—	—	16.7(16)
Moderate	5.7(14)	—	—	55.0(50)*	11.7(15)
High	—	—	—	—	—
Total	7.7(10)	20.3(17)	—	5.5(5)	2.6(9)
<i>C. limosa</i>					
Low	6.7(27)	26.0(44)*	8.7(20)	1.0(16)	10.3(29)
Moderate	6.3(43)	—	—	—	3.3(23)
High	7.7(43)	7.0(29)	—	3.0(8)	6.0(29)
Total	7.0(36)	15.7(33)	4.8(11)	2.3(10)	7.5(28)
<i>Number of Stations</i>					
Low	22	2	5	6	42
Moderate	7	2	2	2	13
High	21	7	2	12	42
Total	50	18	9	20	97

\*Indicates presence of a single unusually high value

## DISCUSSION

*Callianassa arenosa*, *C. australiensis* and *C. limosa* are all widely and abundantly distributed in Western Port. However, this study has shown that several factors may be important in determining the patterns of occurrence observed in the bay. Differences in substrate, water depth, extent of seagrass cover and amount of shell debris all appear to influence the distribution and local abundance of the three species examined.

The presence of a moderate to high vegetation cover reduced the frequency of occurrence of all species. The reduction is presumably due to the plants' restriction of the area available for colonisation and to the difficulty in burrowing where seagrass roots are dense. However, it is not clear why *C. arenosa* alone can maintain quite high population densities in vegetated areas. Similarly, the presence of shell debris in the substratum may hinder burrowing but *C. limosa* seems less affected than the other species. Maximum densities of all three species were found in areas with slight vegetation cover, possibly because this provided

a source of organic material and promoted sediment stability.

There was no station at which all three species were found together, but each species did occur with one of the others. Co-occurrences of *C. australiensis* with *C. limosa* (1 station) and of *C. arenosa* with *C. australiensis* (3 stations) were rare. *C. arenosa* and *C. limosa* were found together at sixteen stations. Since *C. arenosa* was found at thirty-seven stations and *C. limosa* at twenty-six, their co-occurrence at sixteen stations indicates a considerable degree of overlap in distribution. In these cases of spatial co-existence one species was generally much more abundant than the other, but patterns of dominance may change with time. A year's survey of a site on the northern tidal flats (Coleman, unpublished) showed that the ratio of *C. arenosa* to *C. australiensis* changed from 1:0.2 to 1:3.3 in six months and then returned to 1:0.2. Such temporal changes may reflect migration between areas or differences in reproductive behaviour.

*Callianassa* were absent from the deeper channel areas, presumably because strong water currents



Fig. 3—Distribution of *Callianassa australiensis* in Western Port. Dots indicate survey stations at which *C. australiensis* was found. The dotted line indicates the 5.5 m depth contour.

and sediment mobility make this environment too unstable. Harder to understand was the absence of *Callianassa* from a large area in the north-east of the bay. Of nine stations in this region, five were quite shelly and/or heavily vegetated but four stations along the Tooradin — Lang Lang coast seemed suitable for *C. arenosa* and *C. australiensis*. This absence may reflect patchiness in distribution, for a subsequent more intensive survey of this area has shown that *C. arenosa* and *C. australiensis* do occur there.

Hailstone and Stephenson (1961) have reported *C. australiensis* in Queensland from gently sloping intertidal flats of fine sand with little mud, and less commonly from other intertidal substrates and the subtidal zone. The distribution of *C. australiensis* in Western Port is similar to that found in Queensland. The densities estimated by Hailstone and Stephenson

(1961) of 250-500 individuals per square metre were considerably higher than those encountered in the present survey, but similar densities have been recorded in Western Port (Coleman, unpublished).

In Port Phillip Bay, *Callianassa arenosa* inhabits silty-sand between 13 and 19 m depth (Poore 1975). In contrast, the greatest densities of this species in Western Port were in the intertidal to immediate-subtidal zone, but the sediment preferences displayed are similar. In both bays *C. arenosa* avoid the deepest sediments although in Port Phillip Bay these were of fine silty-clay and in Western Port coarse shelly sand. *Callianassa limosa* is the deepest occurring species in both Port Phillip Bay (Poore 1975) and Western Port. In both bays the species was found in stable sediments; in Port Phillip Bay these are of mud, largely free of shell debris and plants, but in Western Port they are





Fig. 4—Distribution of *Callianassa limosa* in Western Port. Dots indicate survey stations at which *C. limosa* was found, dotted line the 5.5 m depth contour.

poorly sorted coarser sediments, sometimes bound by plants (*Caulerpa* spp.). In Port Phillip Bay *Callianassa australiensis* is uncommon.

Three other species of *Callianassa* have been reported from Western Port. *C. ceramica* Fulton and Grant is common in Port Phillip Bay (Poore 1975) but is known only from Shoreham and San Remo ocean beach in Western Port (Poore & Griffin 1979). *C. aequimana* Baker has been collected from Shoreham and Crib Point and *C. tooradin* Poore and Griffin is known from four specimens collected at Crib Point in 1965 (Poore & Griffin 1979). None of these species was found in the present survey.

#### ACKNOWLEDGMENTS

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## VEGETATION OF AN INFREQUENTLY BURNED TASMANIAN MOUNTAIN REGION

By J. B. KIRKPATRICK\* AND C. E. HARWOOD\*

**ABSTRACT:** The Mt. Bobs-Boomerang area in southern Tasmania is rugged and mountainous (600-1080 m above sea level), with a perhumid cool (Thornthwaite classification) climate and a range of geological substrates including mudstone, sandstone, limestone and dolerite. 164 species of vascular plants, all native to Tasmania, have been recorded in the study area. The subalpine vegetation is composed primarily of rainforest and scrub communities. Fires have had major effects on these communities, but are rare; the period since the last fire varies between about 50 and 500 years. A small area of herbland and heathland occupies the poorly drained valley floors and different herbland communities are found on the flats and limestone cliffs around Lake Sydney.

Above the treeline, which occurs at about 1000 m on Mt. Bobs and the Boomerang, heathland is the major vegetation formation. Herblands are found in sheltered sites with the longest snowlie, and fjaeldmark, much of it associated with a pattern of non-sorted solifluction terraces, occupies the highest, most exposed part of the mudstone-capped Boomerang.

Exposure to strong winds, snowlie, substrate type, degree of waterlogging and fire frequency appear to be major environmental determinants of the plant communities.

### INTRODUCTION

Fifty-five per cent of the high mountain country of Australia lies within Tasmania (Costin 1973). The Tasmanian high mountain vegetation differs markedly from that of the mainland. It is more Antarctic (Stones & Curtis 1967) than Australian in its floristic affinities and largely dominated by shrubs rather than grasses and forbs. Jackson (1973) has described the varied vegetation of the Central plateau, and Sutton (1928) has described part of the vegetation of the plateau and peaks of the Cradle Mountain-Lake St. Clair National Park. These two regions form the largest contiguous area of high mountain vegetation in Australia. The vegetation of the outlying high dolerite plateaux of the northeast of Tasmania is undescribed, and among the numerous 'islands' in the high mountain archipelago to the south and west of the Central Plateau (Fig. 1) only the vegetation of Mt. Field (Davies 1978), the West Coast Range (Kirkpatrick 1977) and Mt. Wellington (Martin 1940, Ratkowsky & Ratkowsky 1976, 1978), are reasonably well-documented. One of the major gaps in the literature of Tasmanian high mountain vegetation is the complete lack of any published work relating to the South-West, where the mountains are concentrated in the eastern part of the largest wilderness area in temperate Australia.

Mountains such as the Eastern and Western Arthur Ranges, Precipitous Bluff, Mt. Anne and Mt.

Bobs are becoming increasingly used for wilderness recreation, and at the same time the distance between them and areas of intensive land use and easy access is shrinking. Much of their vegetation is ill-adapted to fire and trampling yet is of intense scientific interest, since it is largely dominated by endemic and/or Antarctic elements of the Tasmanian flora. These elements have been seriously reduced in area and richness on many of the mountains of Tasmania by the firing and logging that has taken place since white settlement (Jackson 1973, Kirkpatrick 1977a, 1977b).

Of the mountains of the South-West only the Mt. Anne massif and the Mt. Bobs-Boomerang complex still retain large diverse areas of Antarctic vegetation. All other ranges of the South-West have been burnt over in the last two centuries, although none lack remnants of their original vegetation. The Mt. Anne and Mt. Bobs areas have avoided fire because of their remoteness from humans, the presence of topographic barriers and because they are surrounded on most sides by large areas of relatively non-inflammable (Jackson 1968) temperate rainforest. Their isolation has decreased in the last decade, with a large hydro-electric scheme and roading near Mt. Anne, and the extension of logging into the Picton Valley near Mt. Bobs. Logging is likely to advance closer to both mountains, and would bring with it an increased fire risk.

This article provides a preliminary account of

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the vegetation patterns and processes in the Mt. Bobs-Boomerang complex (Fig. 2).

### THE AREA

The Mt. Bobs plateau reaches a height of 1000-1080 m above sea level (Fig. 2). It consists of a sill of Jurassic dolerite whose margins form steep slopes in all directions. The Boomerang has a smaller

area above 1000 m. It is immediately adjacent to Mt. Bobs, separated from it by a steep saddle. It is geologically quite distinct from Mt. Bobs, having been carved in Permian sediments that are bedded almost horizontally, with a dip of about 5° to the east. A thin capping of mudstone overlies sandstone on the 'bend' of the Boomerang, but wedges out about one-third of the way along each 'arm', beyond which points the more resist-

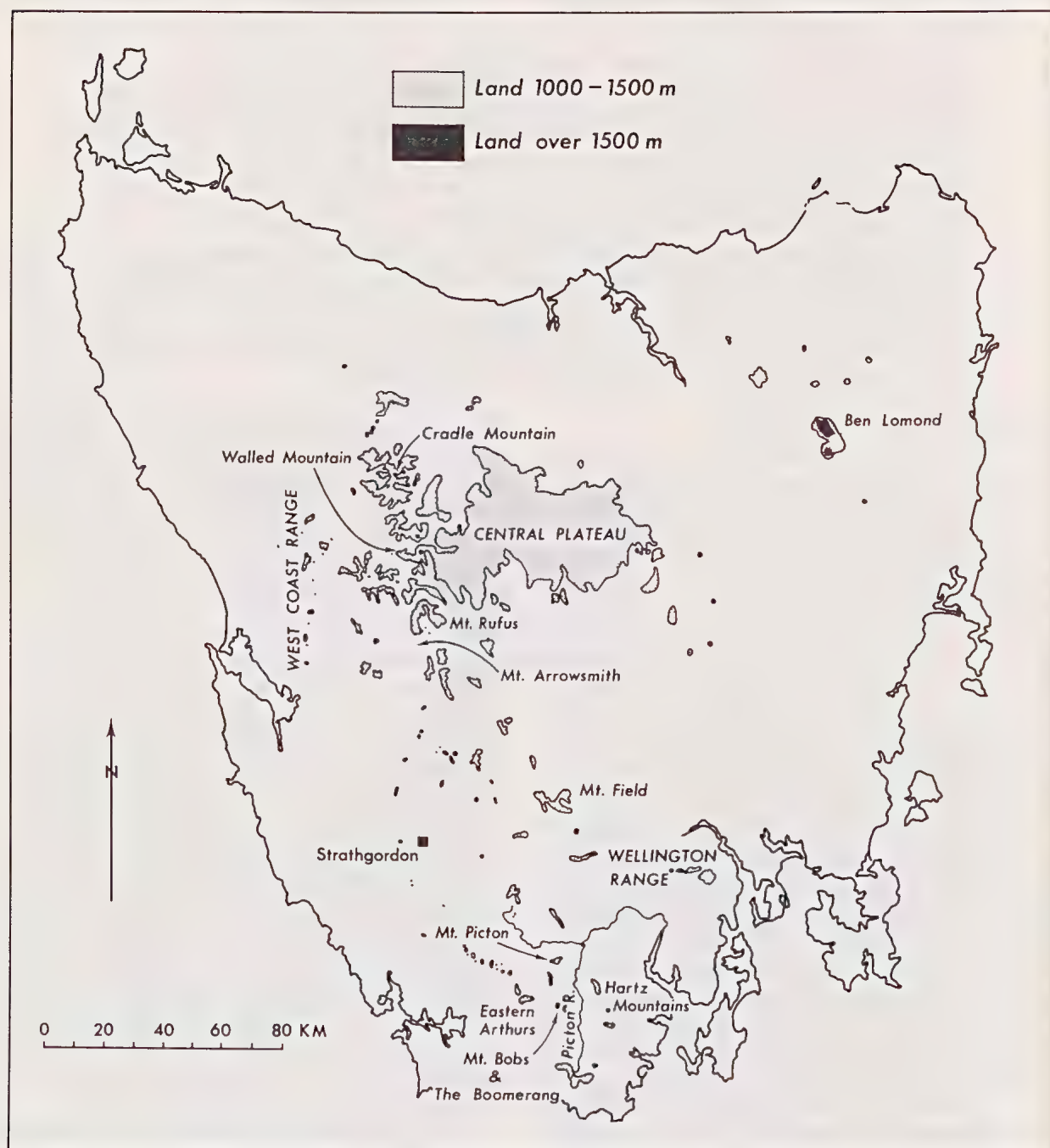


Fig. 1 — High mountain areas of Tasmania.

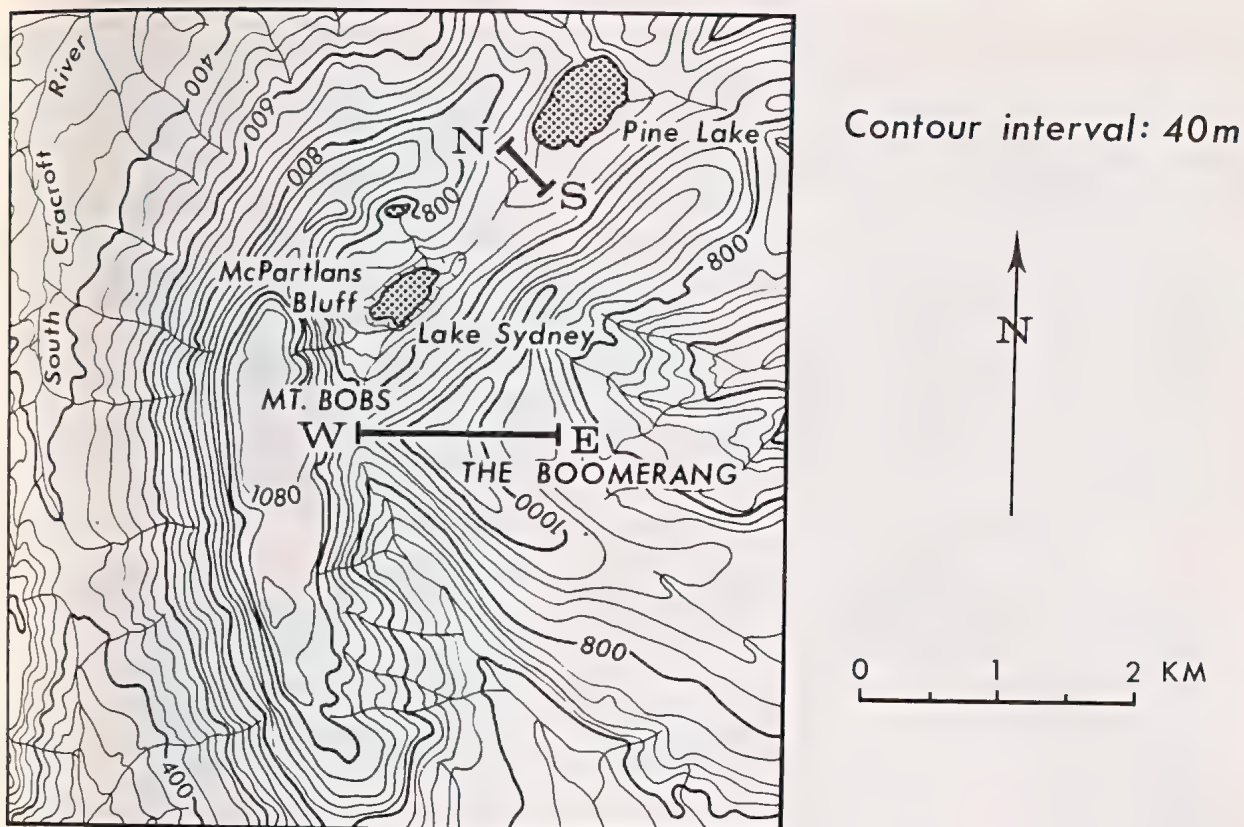


Fig. 2 — Topographic map of the Mt. Bobs-Boomerang area showing the location of the transects (Figs. 6 and 7).

tant sandstone is exposed. Differential erosion of the sedimentary strata has produced a series of plateaux and cliffs surrounding the ridge of the Boomerang and extending down to 600 m above sea level. The valley extending to the northeast of Mt. Bobs and bounded to the southeast by the northern 'arm' of the Boomerang has been glaciated, and till overlies the bedrock along most of its length. It is only around Lake Sydney that Gordon limestone is exposed in a few cliffs, valleys, and a sinkhole which drains Lake Sydney and its catchment. When full, this sinkhole is contiguous with Lake Sydney and has a depth of over 15 m. When the water level drops by more than 2 m, Lake Sydney and the sinkhole become separated, the outflow from the lake draining by a creek into the sinkhole. The sinkhole can fill in a single day following heavy rain, and empty

just as rapidly. This unusual drainage system results in fluctuations in the level of the sinkhole and the upper 2 m of Lake Sydney of a greater order of magnitude and much shorter periodicity than those that occur in most lakes in the humid west of Tasmania. Pine Lake, the other major water body in the valley, drains to the northeast in the normal manner.

No climatic data are available from sites in or near the study area. The precipitation patterns experienced at Hartz Mountains and Strathgordon (Fig. 1) are shown in Table 1. Precipitation in the study area is probably intermediate between that of these two sites. More than three consecutive days without precipitation is exceptional, judging from the accounts of parties that have visited the area. In common with other Tasmanian mountains, Mt. Bobs and the Boomerang can

TABLE 1  
PRECIPITATION DATA FOR STRATHGORDON (8 YEARS) AND HARTZ MOUNTAINS (12 YEARS)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Strathgordon													
Mean (mm)	137	96	137	234	272	257	294	267	292	207	194	243	2630
Raindays	17	11	16	21	22	23	25	23	22	21	19	24	244
Hartz Mountains													
Mean (mm)	91	95	116	184	205	152	146	139	182	142	142	113	1707



receive a covering of snow at any time of the year, and the exposed plateaux and mountain tops are subject to strong and persistent westerly winds. Snow lies in drifts on lee slopes and in hollows near the mountain summits for about 4-5 months in average years, but the period of continuous cover is considerably shorter for most of the area.

The Mt. Bobs-Boomerang alpine complex forms an island of open vegetation among a sea of temperate rainforest and rainforest scrub (Fig. 3). The only species of eucalypt found in the study area is *Eucalyptus vernicosa*, a shrub sized subalpine species able to regenerate in the open conditions at high altitude without the intervention of fire.

## METHODS

The vegetation of the area shown in Fig. 4 was

mapped from interpretation of vertical aerial photographs and ground survey undertaken in December 1977. The fire boundaries shown in Fig. 4 were evident on both the photographs and on the ground from the skeletons of *Athrotaxis selaginoides* and height differences in the vegetation.

Species lists of all gymnosperms, angiosperms and pteridophytes were made at the locations shown in Fig. 5. At each of these sites notes were made of the structure of the vegetation and the species exhibiting the greatest cover in the tallest stratum. Species not found at these locations but occurring within the study area were also listed and/or collected. The species observed in the area mapped in Figs. 4 and 5 are listed in the Appendix. Taxonomic nomenclature follows Curtis (1963, 1967) and Curtis and Morris (1975) for gymnosperms and dicotyledons and Willis (1970) for

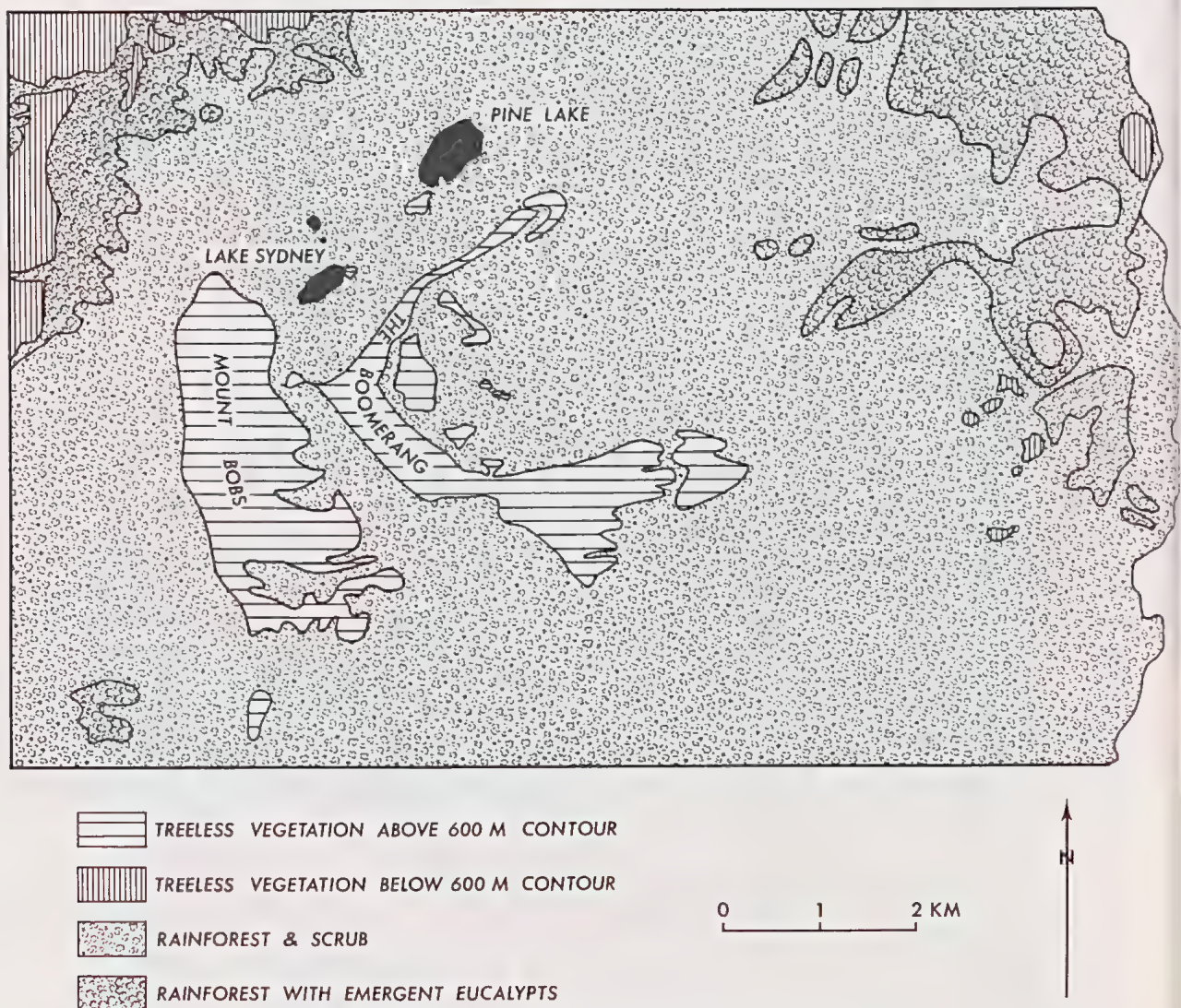


Fig. 3 — Vegetation map of the area surrounding the mountains.

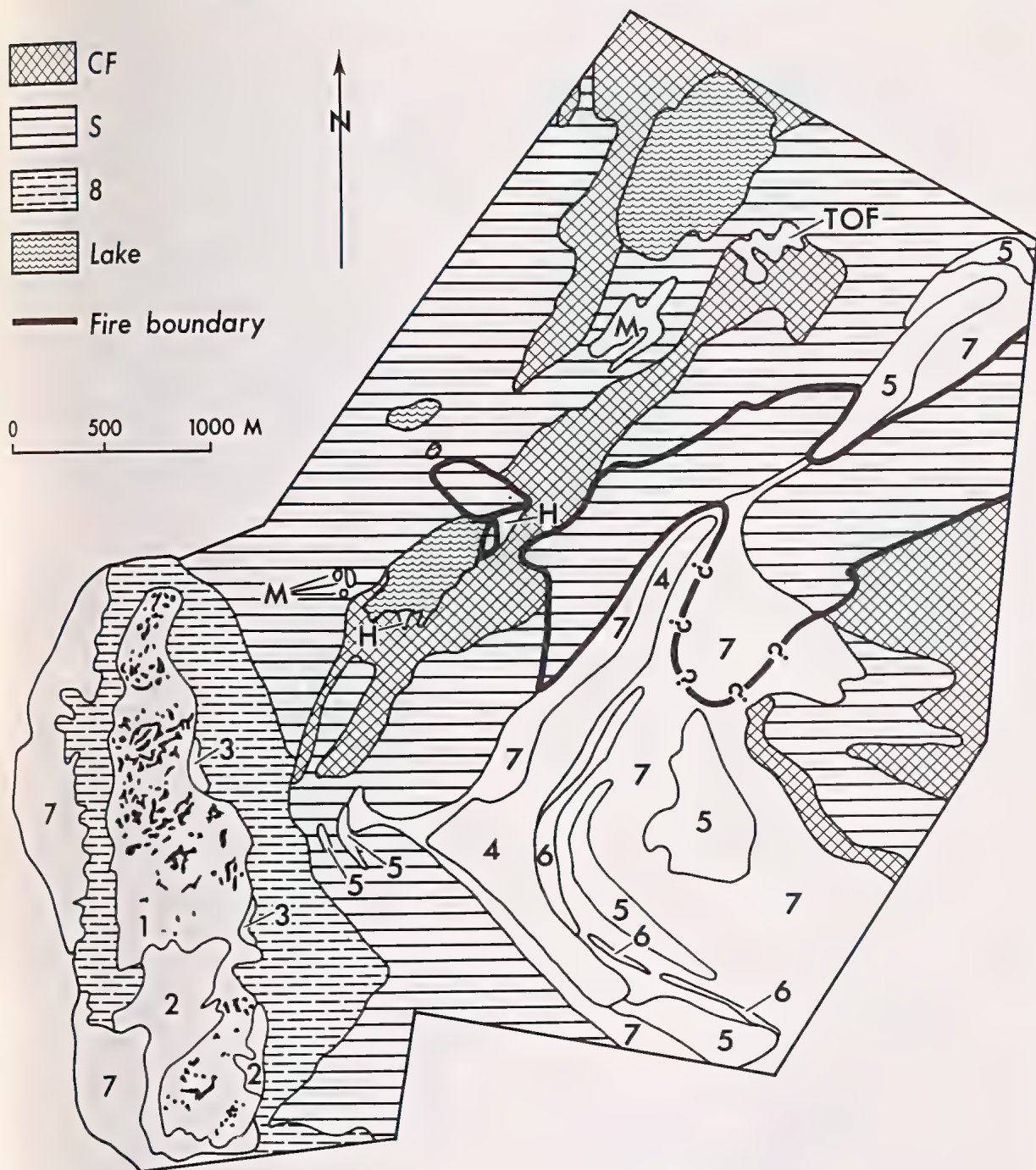


Fig. 4 — Vegetation mapping units, and fire boundaries.

TOF = *Athrotaxis selaginoides* tall open-forest; CF = *A. selaginoides*-*Nothofagus cunninghamii* closed-forest; S = low closed-forest and closed-scrub; H = closed-herbland; M = moor (see Fig. 6 for structural types); 1 = Low-heath and low shrubland. The white areas are low closed-heath and low-shrubland. The black areas are low open-shrubland in waterlogged depressions; 2 = *Diselma archeri*-*Bellendena montana* heath; 3 & 6 = *Milligania densiflora*-*Astelia alpina* herbland; 4 = Fjaeldmark and low closed-heath on mudstone; 5 = *Donatia novae-zelandiae*-*Oreobolus pumilio* low closed-heath on sandstone; 7 = *Richea scoparia*-*Nothofagus cunninghamii* closed-heath; 8 = *Diselma archeri*-*Bellendena montana* heath and over 50% bare rocks.



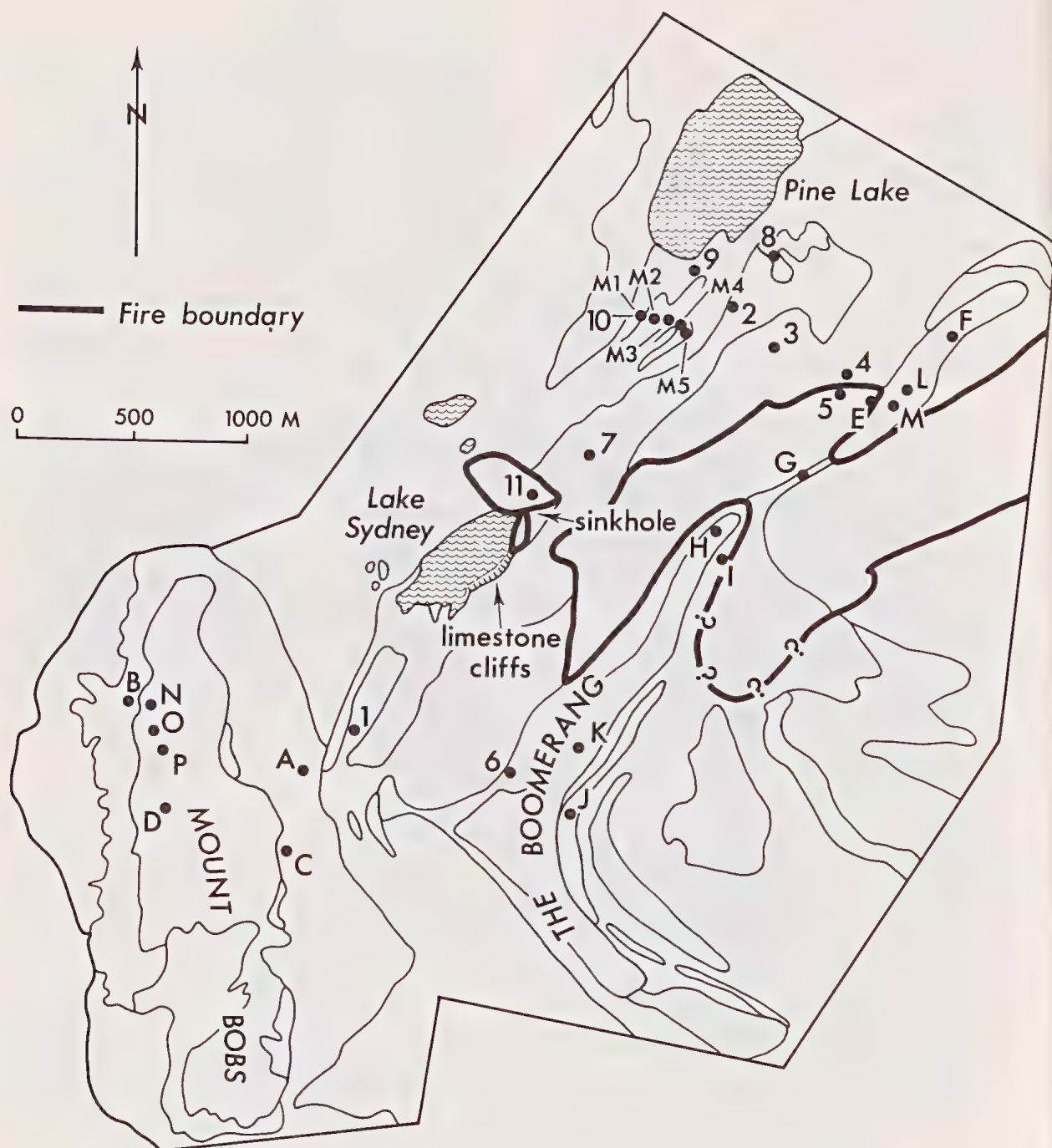


Fig. 5 — Locations referred to in Tables 2 and 5, and in the text.

monocotyledons and pteridophytes, except where other authorities are given in the Appendix. Structural nomenclature follows Specht (1970) except that the term 'fjaeldmark' is used in the sense of Barrow *et al.* (1968) and heath and closed-heath are used to describe vegetation 0.2-2 m tall with the prefix 'low' denoting heath less than 0.2 m tall.

The site species lists were formed into site-species matrices for the forest-scrub and treeless areas. These matrices were successively re-sorted to form species-site blocks. The point-centred quarter method (Mueller-Dombois & Ellenberg 1974) was used to obtain density and basal area figures for the *Athrotaxis selaginoides* tall open-forest near Pine Lake. The tree diameter at breast height and distance from the point were measured for trees greater than 10 m tall, and the height of each tree estimated. For shrubs and trees between 0.5 and 10 m tall distance from the point was measured and height estimated. These measurements and estimations were made on four trees and shrubs at each of twelve points located non-purposively within relatively uniform forest. Increment cores were taken from several trees in this and other areas to obtain information on age and growth rate.

#### VEGETATION DOMINATED BY TREES AND TALL SHRUBS

Trees and tall shrubs generally extend upwards to an altitude of 1000 m. Their absence above this altitude appears to be attributable to the effects of exposure, rather than to low temperature, as a few flag-form, shrub-sized *Athrotaxis selaginoides* are found at about 1000 m on the more sheltered slopes of both mountains. The most wind-exposed and/or poorly drained areas below 1000 m are treeless.

The vegetation map discriminates between tall open-forest, closed-forest and scrub (Fig. 4). The latter two of these mapping units contain a diversity of vegetation that was not practical to map. Table 2 shows some of the range of floristic variation in the forest and scrub of the area. The most frequent species (Group A, Table 2) are those typical of high altitude forest and scrub communities where fire is a rarity (Sutton 1928, Kirkpatrick 1977). The species in Group B and C are those of the closed-scrub and closed-forest of steep sites with shallow soils. These communities are much richer in species than the forests of better sites. Group F consists of species that typically occur in the high altitude heaths and herblands, but which are found in the lower strata of the high altitude scrub communities that have not completely recovered from fire. Groups E and G are typical of open communities found in areas with impeded drainage.

Four species dominate almost all the forest and

scrub in the study area: *Athrotaxis selaginoides*, *Nothofagus cunninghamii*, *N. gunnii* and *Leptospermum nitidum*, the latter being a sparse emergent over communities dominated by *Nothofagus* species (e.g. Fig. 6). The major communities, defined on a basis of structure, dominance and species composition are:

##### a) *Athrotaxis selaginoides* TALL OPEN-FOREST

This community is restricted to an area of about 5 ha south of Pine Lake (Fig. 4) where it occurs on moderate slopes on sandstone till. The uppermost stratum has a cover of about 50% and is occupied entirely by *A. selaginoides*, which reaches heights of 25-35 m. The trees lean in a variety of directions at angles of up to 15° from the vertical, but most are straight and single-boled with a narrow crown accounting for about one fifth of the height.

The second stratum in the forest consists of *Nothofagus cunninghamii* and *Atherosperma moschatum* which are 15-25 m tall and collectively have a cover of approximately 10%. Many trees in this intermediate height class are dead or appear to be dying back. *Richea pandanifolia* 5-15 m tall forms a sparse third stratum with approximately five per cent cover. The fourth stratum, which has a cover of approximately twenty-five per cent, consists largely of spreading, 2-3 m tall shrubs of *Archeria eriocarpa*. There is abundant regeneration of *Nothofagus cunninghamii*, *Atherosperma moschatum* and *Phyllocladus aspleniifolius*, mainly concentrated on logs.

The floristic composition of the stand (8) is shown in Table 3 where the dominance of *A. selaginoides* is testified by the measurements shown. The trees of this species are not only taller than those of *N. cunninghamii* and *A. moschatum*, they are also concentrated in larger basal area classes. Although the basal areas of individuals of *A. selaginoides* vary markedly there appears to be less variation in age. Ring counts on increment cores taken at breast height from 8 trees with d.b.h.'s ranging from 43 to 175 cm were made and minimum ages of 350 to 447 years obtained. In all cases the actual age would be considerably higher, as the species takes several decades to reach breast height, averaging 42 years old at 1 m for stands near Mt. Field (Ogden 1978). Two trees may have been considerably older as the centre was not reached with the increment core.

##### b) *Athrotaxis selaginoides*-*Nothofagus cunninghamii* CLOSED-FOREST

This community constitutes most of the area of closed-forest mapped in Fig. 4. It occurs on soils formed on limestone, glacial till and sandstone. *A. selaginoides* usually accounts for 10-30% of the cover in the dense canopy, *N. cunninghamii* providing the rest. There is generally a sparse second layer consisting



TABLE 2  
SUBALPINE FOREST AND SCRUB COMMUNITIES

		Site (see Figure 5)											
		7	8	6	5	1*	2	3	4	9	12	11*	10
		CF	TOF	CS	CS	CS	LCF	CS	LCF	CS	OS	OS	OS
A	<i>Eucryphia milligani</i>	x	x	x	x	x	x	x	x	x	x	x	x
	<i>Nothofagus cunninghamii</i>	x	x	x	x	x	x	x	x	x	x	x	-
	<i>Phyllocladus aspleniifolius</i>	-	x	-	x	x	x	x	x	x	x	x	x
	<i>Orites diversifolia</i>	-	-	x	x	x	x	x	x	x	x	x	x
	<i>Richea scoparia</i>	-	-	x	x	x	-	x	x	x	x	x	x
	<i>Astelia alpina</i>	-	x	x	x	-	x	x	x	x	x	x	x
	<i>Prionotes cerinthoides</i>	x	x	-	x	-	x	-	x	x	x	x	x
	<i>Athrotaxis selaginoides</i>	x	x	x	x	-	-	x	x	x	x	x	-
	<i>Richea pandanifolia</i>	x	x	x	-	x	x	-	x	-	x	x	x
B	<i>Cennarhene nitida</i>	-	-	-	x	x	x	x	x	x	x	-	x
	<i>Richea milligani</i>	-	-	-	x	x	x	x	x	x	x	-	x
	<i>Cyathodes juniperina</i>	-	-	-	x	x	-	x	x	x	x	x	-
	<i>Olearia persoonioides</i>	-	x	-	x	-	x	x	x	x	x	-	-
	<i>Agastachys odorata</i>	-	-	-	x	x	x	x	-	x	x	-	-
	<i>Anodopetalum biglandulosum</i>	-	-	-	-	x	x	x	-	-	x	-	-
C	<i>Archeria hirtella</i>	-	-	-	-	-	x	x	x	-	x	-	x
	<i>Blechnum watsii</i>	-	-	-	-	-	x	x	x	-	-	-	-
	<i>Archeria eriocarpa</i>	x	x	x	-	-	x	x	x	-	-	-	-
D	<i>Trochocarpa cunninghamii</i>	x	-	x	-	-	-	x	x	-	x	x	-
	<i>Drimys lanceolata</i>	-	x	x	x	-	x	-	x	-	x	x	-
E	<i>Leptospermum nitidum</i>	-	-	-	-	x	x	-	-	-	x	x	x
	<i>Lomatia polymorpha</i>	-	-	-	-	x	-	x	-	-	x	x	x
F	<i>Monotoca submutica</i>	-	-	-	x	x	-	-	x	x	x	-	-
	<i>Bauera rubioides</i>	-	-	-	x	x	-	-	-	-	x	-	x
	<i>Diplarrena latifolia</i>	-	-	-	x	x	-	-	-	-	x	-	-
	<i>Persoonia gunnii</i>	-	-	-	x	x	-	-	-	x	-	-	-
	<i>Oreobolus acutifolius</i>	-	-	-	x	x	-	-	-	-	-	-	-
	<i>Epacris serpyllifolia</i>	-	-	-	x	x	-	-	-	-	-	-	-
	<i>Calorophus elongatus</i>	-	-	-	x	x	-	-	-	-	-	-	-
G	<i>Nothofagus gunnii</i>	-	-	-	-	-	-	-	-	x	x	-	x
	<i>Tetracarpaea tasmanica</i>	-	-	-	-	-	-	-	-	x	x	x	-
	<i>Gahnia grandis</i>	-	-	-	x	-	-	-	-	x	-	-	x
	<i>Microlaena tasmanica</i>	-	-	-	x	-	-	-	x	-	-	x	x
	<i>Coprosma nitida</i>	-	-	-	-	-	-	x	x	-	-	x	-
	<i>Telopea truncata</i>	-	-	-	-	x	-	x	-	-	x	-	-
	<i>Diplaspis cordifolia</i>	-	-	-	-	-	-	-	-	-	-	x	-
Number of species		7	13	12	27	23	18	20	21	17	28	20	16

Additional species: *Acaena novae-zelandiae* (11), *Anopterus glandulosus* (2), *Atherosperma moschatum* (8), *Bellenden montana* (11), *Blandfordia punicea* (5), *Exocarpos humifusus* (5), *Gleichenia dicarpa* (5), *Grammitis billardieri* (8), *Lycopodium fastigiatum* (12), *Olearia pinifolia* (6), *Oxalis lactea* (11), *Sprengelia incarnata* (1), *Stylidium graminifolium* (1).

(\* = Burnt within last 100 years, TOF = tall open forest, CF = closed forest, LCF = low closed forest, CS = closed scrub, OS = open scrub)

N

S

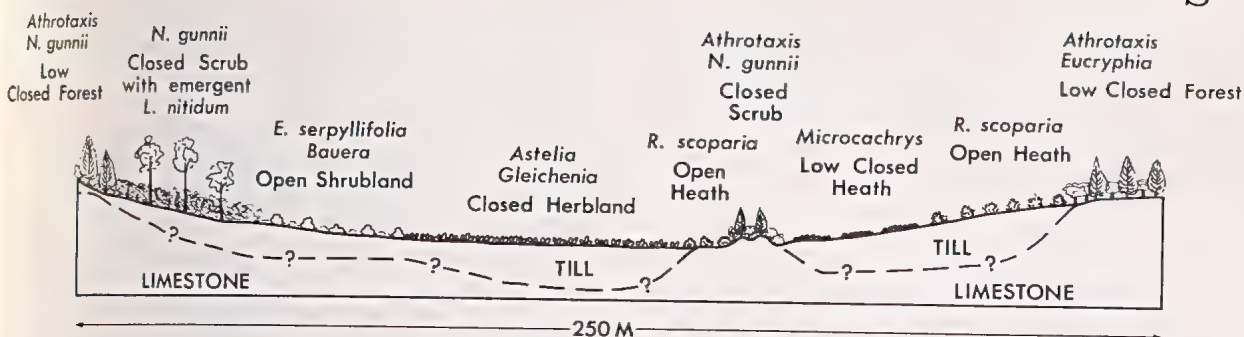


Fig. 6 — Transect across Pine Lake moor.

of *Eucryphia milliganii* and *Richea pandanifolia* 3-8 m tall, and a sparse third layer dominated by 1-3 m tall *Archeria eriocarpa*. Mosses, lichens and filmy ferns cover almost every surface in the humid sub-canopy micro-environment. The number of species of vascular plants is generally less than 10 (e.g. 7, Table 2), and the forest floor is extremely open.

c) *Nothofagus cunninghamii* CLOSED-FOREST

This community is restricted to some of the deeper valleys to the southwest of Lake Sydney. It is similar in its characteristics to the preceding community except that *A. selaginoides* is absent, *Atherosperma moschatum* is much more common and the second layer described above is often absent.

d) *Athrotaxis selaginoides*-*Nothofagus cunninghamii* LOW CLOSED-FOREST TO CLOSED-SCRUB

This community is widespread in the area mapped as closed-scrub, but is concentrated on well-drained, rocky upper slopes and is absent from within the burnt areas marked in Fig. 4. The community is generally richer in species (e.g. 3, 4, 5 and 6, Table 2) than those previously described, and the upper stratum is shared by species such as *Phyllocladus aspleniifolius*, *Richea pandanifolia*, *Orites diversifolia*, *Cenarrhenes nitida*, *Agastachys odorata*, *Richea milliganii* and *R. scoparia*. The size of normally shrubby species such as *Richea scoparia* is quite remarkable in parts of this community. For instance, near Lake Sydney individuals of this species have a basal diameter of almost 20 cm and are over 6 m tall.

There is typically no distinct understorey-layer, the stratum below the crowns of the dominants being occupied by a tangled mass of moss-covered stems. The ground is also moss-covered with a sprinkling of herbaceous species such as *Astelia alpina* and ferns such as *Blechnum wattsi*.

e) *Nothofagus cunninghamii* CLOSED TO OPEN-SCRUB

This community is restricted to areas where *A. selaginoides* has been unable to re-establish since the

last fire, and is most extensive within the fire boundaries shown in Fig. 4. Site 1 (Table 2) is representative of the more open areas of this community. The ability of *N. cunninghamii* individuals to coppice allows them to survive fires which would kill *Nothofagus gunnii*, *Athrotaxis selaginoides* and *Phyllocladus aspleniifolius*. *Eucryphia milliganii* and *Orites diversifolia* often share dominance with *N. cunninghamii*.

f) *Athrotaxis selaginoides*-*Nothofagus gunnii* OPEN-SCRUB

This community occurs on south-facing slopes where the soil is more or less constantly moist as a result of seepage through terminal moraines on gentle slopes. It is absent from the northern slopes of the Boomerang. Sites 9 and 12 (Table 2) are typical of the community which is the richest of all the forest and scrub communities in tree and scrub species. *Nothofagus gunnii*, the only Australian winter-deciduous tree species, forms most of the cover in the tallest stratum. The other species most common in this stratum are *A. selaginoides*, *Phyllocladus aspleniifolius* and *N. cunninghamii* but they collectively constitute less of the cover than *N. gunnii*. The understorey consists of a tangled mass of stems of the dominants interspersed with pungent-leaved shrubs of varying sizes and shapes. As with all the forest and scrub communities the ground and lower stems are densely covered by mosses and lichens. *A. selaginoides* is absent from the community where drainage is poor. In these locations occasional emergent individuals of *Leptospermum nitidum* are found.

## VEGETATION DOMINATED BY SHRUBS AND/OR HERBS

### (a) THE LAKE SYDNEY HERBFIELDS

The sinkhole and the upper zone of fluctuating waterlevel around Lake Sydney carry a distinctive herbaceous vegetation. At the sinkhole *Hydrocotyle muscosa* and moss are found over the full range of water-



TABLE 3  
CHARACTERISTICS OF THE *Athrotaxis selaginoides* TALL OPEN-FOREST NEAR PINE LAKE

Species	Mean Height (m)	% relative abundance	Density per 100 m <sup>2</sup>	Basal area (m <sup>2</sup> /ha)	% frequency by basal area class (cm <sup>2</sup> )				
					0-1000	1001-2000	2001-3000	3001-4000	4001 +
Trees > 10 m									
<i>Athrotaxis selaginoides</i>	28	52	5.1	150	12	36	24	4	24
<i>Nothofagus cunninghamii</i>	21	36	3.4	64	18	41	29	12	-
<i>Atherosperma moschatum</i>	16	12	1.2	5	100	-	-	-	-
Shrubs and trees 0.5-10 m									
<i>Richea pandanifolia</i>	3.2	15	8.5						
<i>Archeia eriocarpa</i>	1.9	65	37.8						
<i>Nothofagus cunninghamii</i>	1.0	8	4.8						
<i>Eueryphia milligani</i>	1.7	4	2.4						
<i>Atherosperma moschatum</i>	5.0	4	2.4						
<i>Phyllocladus aspleniifolius</i>	1.5	2	1.2						
<i>Olearia persoonioides</i>	2.0	2	1.2						

levels. Near the highest levels *Juncus subsecundus*, *Ranunculus collins* and *Bellenden montana* are conspicuous. Near the base of the sinkhole depression *Blechnum penna-marina* and *Haloragis montana* occur as occasional individuals on small cliffs.

Along the shores of Lake Sydney zones dominated by *Juncus subsecundus*, *Bellenden montana* and *Hydrocotyle muscosa* can be distinguished. Where the shore forms a gentle slope small trees of *Leptospermum nitidum* are found at the rear of the *H. muscosa* herbland.

Around much of the lake shore the limestone bedrock is overlain by dolerite rubble derived from the Mt. Bobs range. However, there are limestone cliffs along the southern shore which carry a floristically distinct vegetation on ledges and in crevices. This vegetation consists largely of ferns, grasses and forbs. Twenty-four of the thirty-three species recorded for the limestone cliffs and shores of Lake Sydney and the sinkhole were not recorded elsewhere in the study area (Appendix), and soft herbaceous species are virtually confined to the limestone.

#### (b) THE PINE LAKE MOOR

The moor near Pine Lake (Fig. 4) differs markedly in character from the treeless areas around Lake Sydney. Its treeless nature appears to be maintained by the impedance of drainage caused by the deposition of till in the flattest part of the valley. The moor, although only about 5 ha in area, contains a wide diversity of communities (Table 4, Fig. 6). *Astelia alpina*-*Gleichenia alpina* closed-herbland occurs in the lowest-lying part of the moor. Parts of this community were covered by water in early summer (November and December 1977). In situations with slightly better drainage there is an *Epacris serpyllifolia*-*Bauera rubioides* open shrubland with a herbaceous understorey dominated by *Astelia alpina* and *Gleichenia alpina*. With further improvement in drainage, *Microcachrys tetragona* dominates a low closed-heath on gentle (up to 5°) slopes in the southern part of the moor. Here the ground is gently undulating, and *M. tetragona* spreads over the low (10-20 cm) hummocks, the depressions being occupied by *Astelia alpina*, *Calorophus minor*, *Sprengelia incarnata* and *Carpha alpina*. Further upslope, *Richea scoparia* forms an open heathland in which *Microcachrys* is almost completely absent, although the understorey is in other respects very similar. The structural boundaries between these four communities are sharp, but floristically they intergrade. The species found in the moor are all common in alpine vegetation throughout the State.

The Pine Lake moor grades into scrub and forest in a mosaic fashion to the east, and more ab-

TABLE 4  
THE RELATIVE ABUNDANCE\* OF SPECIES IN THE ZONES  
OF THE PINE LAKE MOOR

Species	Zone (see Figure 5)				
	1	2	3	4	5
<i>Astelia alpina</i>	c	vc	d	vc	vc
<i>Gleichenia alpina</i>	-	vc	c	r	vc
<i>Carpha alpina</i>	-	c	o	vc	vc
<i>Sprengelia incarnata</i>	-	c	o	vc	vc
<i>Drosera arcturi</i>	-	o	c	o	r
<i>Calorophus minor</i>	-	c	-	vc	vc
<i>Gaimardia setacea</i>	-	o	-	o	o
<i>Microlaena tasmanica</i>	o	o	-	r	c
<i>Richea scoparia</i>	c	-	-	c	d
<i>Eucryphia milliganii</i>	c	-	-	-	r
<i>Richea pandanifolia</i>	o	-	-	-	o
<i>Nothofagus gunnii</i>	d	-	-	-	-
<i>Orites diversifolia</i>	c	-	-	-	-
<i>Phyllocladus aspleniifolius</i>	c	-	-	-	-
<i>Archeria hirtella</i>	o	-	-	-	-
<i>Cenarrhenes nitida</i>	o	-	-	-	-
<i>Richea milliganii</i>	o	-	-	-	-
<i>Gahnia grandis</i>	o	-	-	-	-
<i>Prionotes cerinthoides</i>	r	-	-	-	-
<i>Bauera rubioides</i>	c	d	c	-	-
<i>Lomatia polymorpha</i>	c	r	-	-	-
<i>Leptospermum nitidum</i>	o	o	-	-	-
<i>Diplaspis hydrocotyle</i>	-	o	-	-	-
<i>Diselma archeri</i>	-	o	-	-	-
<i>Epacris serpyllifolia</i>	-	d	r	-	-
<i>Juncus subsecundus</i>	-	o	o	-	-
Cyperaceae sp.	-	o	c	-	-
<i>Senecio pectinatus</i>	-	-	r	-	-
<i>Schizaea fistulosa</i>	-	-	-	r	-
<i>Microcachrys tetragona</i>	-	-	-	d	r
<i>Oreobolus pumilio</i>	-	-	-	c	c
<i>Athrotaxis selaginoides</i> (seedlings)	-	-	-	r	r
<i>Mitrasacme montana</i>	-	-	-	c	o
<i>Pentachondra pumila</i>	-	-	-	c	vc
<i>Actinotus moorei</i>	-	-	-	c	c
<i>Coprosma moorei</i>	-	-	-	o	c
Herbaceous Compositae sp.	-	-	-	c	vc
<i>Actinotus suffocata</i>	-	-	-	r	r
<i>Coprosma nitida</i> (seedlings)	-	-	-	-	r

\* d = dominant and abundant  
vc = very common  
c = common

o = occasional  
r = rare



ruptly in other directions. The openings at the forest edge vary greatly in their character, although the ground surface is generally hummocky, with organic hummocks up to 1.5 m in height and diameter, covered by a *Pentachondra pumila-Calorophus minor* mat heath. Between the hummocks, *Astelia alpina*, the endemic fern *Gleichenia abscida* or *Epacris serpyllifolia* may dominate the ground cover. Shrub-sized *Richea scoparia* and *R. milliganii* are frequent in the openings.

The hummocks may partly derive from variations in the till surface, but seem mainly to have a biological origin. Examination suggested that most are formed when the stumps of dead trees or shrubs act as an anchoring medium for mosses, lichens and higher plants, whose wastes, combined with the decomposition products of the stumps, produce the organic mounds.

#### (c) THE HIGH ALTITUDE HEATHS AND HERBFIELDS

Vegetation dominated by dwarf, prostrate and bolster shrubs covers most of the two mountains (Fig. 4). However, taller heaths are extensive where shelter from the wind is provided by boulders in the better drained areas, and herbfields are found in snow lie situations on both mountains (Fig. 4).

At least eight distinct species associations are found in the high altitude heaths and herbfields (Table 5). The sequence from associations A to F relates to an edaphic sequence from water-logged, peaty shallow soils to well drained, deep mineral soils. Exposure to wind, period of snow lie and parent rock also influence the species composition of the vegetation. Those species in groups A and B characterize the low closed-heath communities dominated by bolster plants. This association generally occurs in areas of low relief and poor drainage, although it is also represented at site J, a steep snow lie area in the lee of the Boomerang. At the other extreme, the taller closed heath of group H is best developed on the edges of the mountain plateaux where weathering has produced deep rocky soils and drainage is free, although seepage provides a high moisture availability. Group E species characterize sites where drainage is free but there is more of a tendency towards drought than at the group H sites, with group F sites appearing intermediate in their characteristics between those of E and H.

Of the associations shown in Table 5, C, D and E are confined to the Boomerang and H is most widespread on Mt. Bobs. Associations A, B, F and G are found on both mountains. The two mountains are floristically distinct. Of the 115 species found in the high altitude heaths and herbfields of the study area 39 were found only on the Boomerang and 8 were confined to Mt. Bobs (Appendix). The physiognomy and

patterning of vegetation on the two mountains is also markedly different. The peculiar properties of the contrasting parent materials of the two mountains are partly responsible for these differences, through the different substrate characteristics that develop from them.

### THE BOOMERANG

The topographic relationships of most of the communities found on the Boomerang are shown in Fig. 7, and the distribution of broad structural units is shown in Fig. 4.

#### 1. FJAEJDMARK (Low Open-Heath to Low Open-Shrubland)

The fjaelldmark vegetation occurs along the mudstone crest of the Boomerang. It forms stripes which are orientated along the contours on the gentle slopes and associated with the pattern of non-sorted steps described below. On steeper westerly slopes some vegetation stripes are orientated at right angles to the contours. These appear to derive from wind action, typically occurring to the leeward of low outcrops of rock, with the vegetation extending in a tail that tapers off from behind the peak of the rock.

The composition (I and K, Table 5) and dominance of the fjaelldmark vegetation is highly variable. At the summit, where bare rocky ground occupies most of the surface, the species are *Poa gunnii*, forming wind-abraded rings, *Podocarpus lawrencii* and *Richea sprengeloides*, prostrate as if steam-rollered, and the herbaceous species *Dichosciadium ranunculaceum* and *Rubus gunnianus*.

The non-sorted steps of the Boomerang have considerable lateral extent (Pl. 9), some following the contours around the crest for several hundred metres. They are found on all aspects but are most extensively developed on the wide, gentle (5-10°) slopes with northeast and southeast aspects down the 'arms' of the Boomerang. The treads of the steps have a downhill slope of 0-5°, and usually carry no vegetation at all, having a surface cover of mudstone fragments over a mixture of stone fragments and fine silt. Their width varies between 0.5 and 6 m. The risers are fully vegetated, and vary in width between 0.5 and 2 m. They slope downhill at 20-30°, so the treads of the steps are separated elevationally by about 0.2-0.8 m.

On gentle slopes in less exposed situations, including some of the risers of the non-sorted steps, complex matrices of bolster plants form a smoothly undulating cover. Species found in the bolsters include *Abrotanella forsterioides*, *Dracophyllum minimum*, *Pterygopappus lawrencii*, *Donatia novae-zelandiae*, *Mitrasacme archeri* and *Oreobolus pumilio*. *Podocarpus lawrencii* dominates most of the risers. On the



PLATE 9

Non-sorted steps on mudstone, at 1040 m on the Boomerang.

more sheltered steeper slopes, the fjaeldmark is replaced by heaths up to 1 m tall, dominated by shrubs such as *Richea scoparia* and *Eucalyptus vernicosa*.

The migration of fjaeldmark plants to leeward, as the windward edge of their canopy is eroded, has been described for Mt. Twynam, in the Australian Alps, by Barrow *et al.* (1968). This process is also occurring on the Boomerang, both for *Poa gunnii* at the summit, and bolster complexes on exposed slopes at slightly lower altitude (Pl. 10).

2. *Milligania densiflora*-*Astelia alpina* OPEN-HERBLAND

This community occurs to the leeward of the fjaeldmark, on 25-35° slopes near the central bend of the Boomerang (Fig. 7). Its distribution clearly relates to that of late-lying snow. In November 1977 about 1 m of snow covered the community, while snow cover was only patchy elsewhere, and small patches of snow remained in December. The community is widest on the south-facing, less insulated slope.

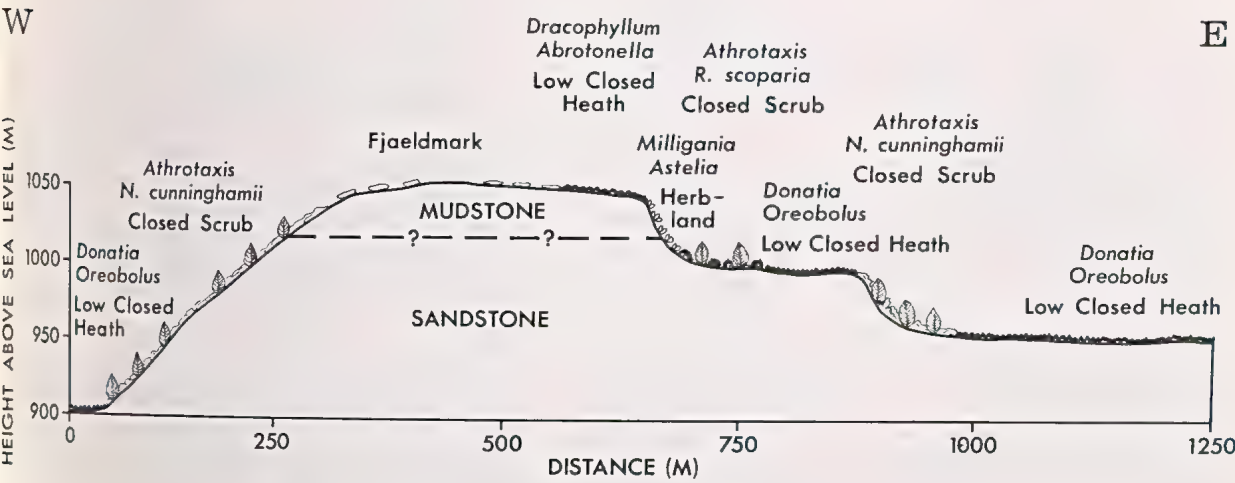


Fig. 7 — Transect across crest of the Boomerang.



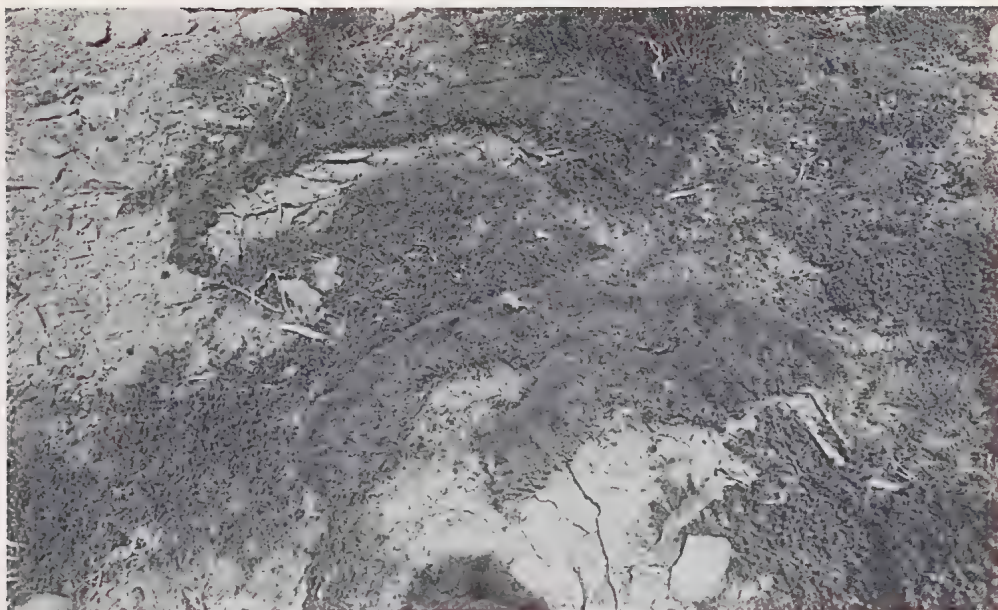


PLATE 10

Bolster complexes eroded to windward and spreading to leeward, at 1060 m on the north west side of the Boomerang.

Only about 60% of the surface is vegetated, and there is evidence of considerable downslope movement of the loose mantle of mudstone weathering products that makes up the substrate. *M. densiflora* and *A. alpina* account for about two thirds of the vegetation cover, with a variable mixture of grasses, sedges, forbs and small shrubs making up the remainder (site J, Table 5). The rare endemic *Geum talbotianum* is concentrated in the upper part of this community, to which it is confined in the study area.

3. *Donatia novae-zelandiae*-*Oreobolus pumilio* Low CLOSED-HEATH

This community occurs on smooth gentle slopes on the sandstone of the Boomerang (Fig. 4; Table 5, sites L and M). The community varies from 4 to 15 cm in height and is dominated by the bolster shrub *D. novae-zelandiae*, the bolster sedge *O. pumilio* and the small leaved shrub *Epacris serpyllifolia*. On the gentlest slopes *Isophysis tasmanica* and *Restio complanatus* and the creeping pine *Microcachrys tetragona* share dominance, as does *Carpha alpina* on slightly steeper slopes. A variety of rosette herbs and prostrate shrubs occur on and between the bolster plants which are usually partly overgrown.

4. *Richea scoparia*-*Nothofagus cunninghamii* HEATH

This community occupies the well-drained parts of the Boomerang not subject to long periods of snow lie (e.g. Fig. 7). The heaths vary in height from 0.1 to 2 m tall and vary in the cover of the tallest stratum from 30 to 100%. Although *Richea scoparia* and *N. cunninghamii* are almost invariably among the

dominants, a highly variable mixture of other species share the tallest stratum. *Nothofagus gunnii* dominates small areas on south and east-facing slopes below the snow patch community and *Athrotaxis selaginoides* is a widespread co-dominant on all but the driest sites and those that have been recently burnt. *Eucalyptus vernicosa* and *Eucryphia milliganii* are also frequent co-dominants. *Epacris serpyllifolia*, *Bauera rubioides*, *Cyathodes parvifolia*, *Coprosma nitida*, *Orites revoluta* and *Celmisia longifolia* are other frequent and widespread members of this community.

MT. BOBS

The vegetation mapping units shown for Mt. Bobs (Fig. 4) mask some marked local variation. For instance, the eastern slopes are vegetated by a mosaic of heaths of varying height, cover and dominance. However, the major variation in the vegetation of Mt. Bobs is between the plateau surface, most of which is covered by a smoothly undulating carpet of bolster plants, and the surrounding slopes on which the predominant cover types are taller heaths and bare rock.

1. *Donatia novae-zelandiae*-*Oreobolus pumilio* Low-HEATH

This is the widespread community of the plateau. Its species composition differs somewhat from the same community on the Boomerang (Table 5, compare N, O and P to L and M). Three variants of this community are evident on Mt. Bobs. On raised mounds (Pl. 11) *Carpha alpina* dominates the in-





PLATE 11

*Donatia novae-zelandiae*-*Oreobolus pumilio* low-heath on Mt. Bobs plateau. *Carpha alpina* (light coloured, curly-leaved sedge), *Dracophyllum milliganii*, *D. novae-zelandiae* and *O. pumilio* are the dominants.

terstices between hummocky bolsters mostly consisting of *Donatia novae-zelandiae* and *Dracophyllum minimum* (e.g. O, Table 5). In lower lying areas the bolster plants form a virtually continuous undulating cover. The species forming the bolsters are *Donatia*, *Dracophyllum minimum*, *Abrotanella forsterioides*, *Pterygopappus lawrencii*, *Ewartia mereditheae*, *Mitrasacme archeri* and *Oreobolus pumilio*. A variety of small and dwarfed shrubs, rosette plants and sedges (e.g. N, Table 5) grows in the cushions. The 20-30 cm deep peat layer is absent from the lowest lying, flat, rocky areas, in which water covers the ground for much of the year (Pl. 12, dark areas in mapping unit 1, Fig. 4). These areas have a sparse (usually less than 10%) cover consisting mainly of cushion and rosette plants (P, Table 5). Most of their surface is covered by flat, plate-like dolerite fragments, aligned horizontally over shallow, rocky soil. These open depressions appear to be diminishing in area, with marginal invasion by bolsters (Pl. 12). No actively enlarging depressions were found, and only a very few areas of breakup of the bolster mat, in the most elevated parts of the community, were evident. The combination of shallow, rocky soil, protracted snow lie, submergence for much of the growing season and severe frost heaving in the open depressions must make re-vegetation extremely difficult. The origin of these open depressions is unknown, but may well derive from the destruction of bolster moor in slight local depressions during exceptionally severe winters, and subsequent oxidation and

ablation of the peat layer. Local relief within this community is insufficient to allow the cyclical process of stream damming by bolsters, heath development after water diversion and eventual reflooding and reversion to bog, proposed for similar communities on the Central Plateau by Jackson (1973). Although fire may have bared the plateau surface in the distant past, it is most unlikely that it would have burnt in the complex pattern evident from Fig. 4, and no evidence of fire was found, so it is considered improbable that fire is a causative factor in the patterning described above.

## 2. *Richea pandanifolia*-*R. scoparia* LOW SHRUBLAND

This community occurs on steeper slopes on the plateau surface, where there is some degree of flushing, with a consequent increase in aeration relative to that in the previous community, and a slight decrease in exposure to the wind. The sparse upper stratum is dominated by the two *Richea* species, which are equal in terms of cover, although *R. pandanifolia*, occurring in its dwarfed alpine form, is more abundant (Pl. 13). About 70% of the lower stratum is occupied by the silvery leaves of *Astelia alpina*, with bolster plants over most of the remainder. The floristic composition of one part of this community, in which the bolster plants were absent, is shown (D, Table 5). The community has not been distinguished from *Donatia novae-zelandiae*-*Oreobolus pumilio* low heath in Fig. 4.



TABLE 5  
ALPINE COMMUNITIES

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A	<i>Mitrasacme archeri</i>	-	-	-	-	-	-	-	-	x	x	x	x	x	-	-
	<i>Abrotanella forsterioides</i>	-	-	-	-	-	-	-	-	x	x	x	-	x	-	x
	<i>Microcachrys tetragona</i>	-	x	-	-	-	-	-	-	x	x	x	x	-	-	-
	<i>Helichrysum milliganii</i>	-	-	-	-	-	-	-	-	x	x	-	-	x	-	x
	<i>Dracophyllum minimum</i>	-	-	-	-	-	-	-	-	x	x	-	-	x	x	-
	<i>Ewartia meredithae</i>	-	x	-	-	-	-	-	-	x	-	-	x	x	-	x
	<i>Actinotus suffocata</i>	-	-	-	-	-	-	-	-	-	-	-	x	x	x	x
B	<i>Astelia alpina</i>	x	-	x	x	x	x	-	x	x	x	x	-	-	x	x
	<i>Carpha alpina</i>	-	x	-	-	-	x	-	x	x	x	x	x	x	x	x
	<i>Sprengelia incarnata</i>	x	-	-	-	-	-	x	x	x	x	x	x	x	x	x
	<i>Oreobolus pumilio</i>	x	-	-	-	-	x	x	-	x	x	x	x	x	x	x
	<i>Donatia novae-zelandiae</i>	-	-	-	-	-	-	x	x	-	x	x	x	x	x	x
	<i>Erigeron stellatus</i>	-	-	-	-	-	x	x	x	x	-	x	x	x	x	x
C	<i>Milligania densiflora</i>	x	-	x	-	-	-	x	x	x	x	-	-	-	-	x
	<i>Haloragis montana</i>	-	x	-	-	x	-	x	x	x	-	-	-	-	-	-
	<i>Richea sprengeloides</i>	-	x	x	-	-	-	x	x	-	x	-	-	-	-	-
	<i>Euphrasia striata</i>	-	x	-	-	-	x	x	-	x	-	-	-	-	-	x
	<i>Podocarpus lawrencii</i>	-	x	x	-	-	-	-	x	x	x	-	-	-	-	-
	<i>Schoenus</i> sp.	-	-	-	-	-	-	x	x	x	-	-	-	x	-	-
D	<i>Poa gunnii</i>	-	-	-	-	-	x	x	-	x	x	-	-	-	-	-
	<i>Diplaspis cordifolia</i>	-	x	-	x	-	x	x	x	x	x	x	-	x	-	-
	<i>Pentachondra pumila</i>	-	x	-	-	x	-	x	x	x	x	-	x	x	-	-
	<i>Oreobolus acutifolius</i>	-	-	-	x	x	-	x	x	x	-	-	-	x	-	-
E	<i>Epacris serpyllifolia</i>	x	x	-	-	x	x	x	x	-	x	x	x	-	-	-
	<i>Nothofagus cunninghamii</i>	x	x	-	-	x	x	x	x	-	-	-	-	-	-	-
	<i>Bauera rubioides</i>	x	-	-	-	x	x	x	x	-	-	x	-	-	-	-
	<i>Cyathodes parvifolia</i>	-	x	-	-	x	x	x	x	-	-	-	-	-	-	-
	<i>Eucalyptus vernicosa</i>	-	-	-	-	x	x	x	x	x	-	-	-	-	-	-
	<i>Celmisia longifolia</i>	-	-	-	-	x	-	x	x	x	-	-	-	-	-	-
	<i>Archeria serpyllifolia</i>	-	x	-	-	x	-	x	-	-	-	-	-	-	-	-
	<i>Coprosma nitida</i>	-	x	-	-	x	x	x	-	-	-	-	-	-	-	-
	<i>Trochocarpa cunninghamii</i>	-	x	-	-	-	x	x	-	x	-	-	-	-	-	-
	<i>Diplarrena latifolia</i>	x	-	-	-	x	-	x	-	x	-	-	-	-	-	-
	<i>Euclerophia milliganii</i>	x	-	-	-	x	x	x	-	-	-	-	-	-	-	-
	<i>Gahnia grandis</i>	x	-	-	-	x	x	-	-	x	-	-	-	-	-	-
F	<i>Orites revoluta</i>	-	x	x	x	x	x	-	x	x	x	x	-	-	-	-
	<i>Richea scoparia</i>	-	x	x	x	x	x	x	x	-	-	-	-	-	-	-
G	<i>Drimys lanceolata</i>	-	x	x	x	x	-	x	x	x	-	-	-	-	-	-
	<i>Calorophus minor</i>	x	-	-	x	x	-	-	x	-	-	-	x	x	-	x
H	<i>Isophysis tasmanica</i>	x	-	-	x	-	-	-	x	x	-	-	x	x	-	-
	<i>Bellenden montana</i>	x	x	x	x	x	-	-	x	x	x	-	-	-	-	-
	<i>Athrotaxis selaginoides</i>	x	x	-	x	x	x	-	-	-	-	x	-	-	-	-
	<i>Diselma archeri</i>	x	x	x	-	x	-	-	-	-	-	x	-	-	-	-
	<i>Orites diversifolia</i>	x	-	x	-	x	-	-	x	x	-	-	-	-	-	-
	<i>Helichrysum backhousei</i>	-	x	-	x	x	-	x	-	x	-	-	-	-	-	-
	<i>Orites acicularis</i>	-	x	x	x	-	-	-	-	-	x	-	-	-	-	-
	<i>Drosera arcturi</i>	x	-	-	-	-	-	x	-	x	-	x	x	-	x	-
	<i>Microlaena tasmanica</i>	-	x	-	x	x	-	-	x	-	x	-	-	-	-	-
	<i>Senecio pectinatus</i>	-	x	-	-	-	-	-	-	x	x	-	-	-	x	x
	<i>Richea pandanifolia</i>	-	-	x	x	-	x	x	-	x	-	-	-	-	-	-
	<i>Uncinia compacta</i>	-	-	x	x	x	-	-	-	x	x	-	-	-	-	-
	<i>Dracophyllum milliganii</i>	x	-	-	-	-	-	-	-	-	-	x	x	-	x	-
Number of species		29	32	15	16	35	18	36	30	33	33	35	21	22	22	12



PLATE 12

*Donatia novae-zelandiae*-*Oreobolus pumilio* low-heath on Mt. Bobs plateau, showing low-lying, partly inundated depression.

3. *Milligania densiflora*-*Astelia alpina* OPEN-HERBLAND

As on the Boomerang, this community occupies areas on the upper eastern slopes where the topography allows snow to accumulate and protects it from wind ablation. The physiognomy and floristics of the community on the two mountains are similar.

4. *Diselma archeri*-*Bellenden montana* HEATH

This community, like the *Richea scoparia*-*Nothofagus cunninghamii* heath of the Boomerang which it most closely resembles, is highly heterogeneous. The species that have been used to name the community are constant (A, B and C; Table 5), but

*Bellenden montana* is never a dominant, and *Diselma archeri* shares the dominant stratum with many other species and is usually their subordinate. On the steep, rocky, upper western slopes of Mt. Bobs *Nothofagus cunninghamii* and *Richea scoparia* dominate a closed-heath. On the steep eastern slopes the dominants include *Nothofagus gunnii*, *Athrotaxis selaginoides*, *N. cunninghamii* and *R. scoparia*. On the most steep and broken areas on top of the plateau *E. vernicosa* is sometimes dominant in mixture with the latter three species and *Diselma*. Two of the mapping units (Fig. 4) include this community, the differentiation being based on the amount of bare rock visible on the aerial photographs.

TABLE 5 (continued)

Additional species: *Abrotanella scapigera* DE, *Acaena montana* JK, *Actinotus moorei* M, *Agastachys odorata* A, *Blandfordia punicea* A, *Blechnum wattsii* I, *Carex* sp. B, *Celmisia saxifraga* K, *Coprosma moorei* J, *Cyathodes dealbata* BK, *Danthonia* spp. JN, *Dichosciadium ranunculaceum* JK, *Euphrasia hookeri* KLN, *Exocarpos humifusus* FGI, *Forstera bellidifolia* FLM, *Gaimardia setacea* O, *Gaultheria hispida* G, *Gentianella diemensis* GJ, *Geum talbotianum* J, *Gleichenia alpina* ALM, *Grammitis armstrongii* J, *Helichrysum pumilum* AM, *Leptospermum nitidum* A, *Lomatia polymorpha* A, *Lycopodium fastigiatum* AM, *L. scariosum* FK, *L. selago* G, *Mitrasacme montana* E, *Monotoca submutica* EG, *Nothofagus gunnii* A, *Olearia ledifolia* BC, *O. pinifolia* BEG, *Ourisia integrifolia* EHI, *Oxalis lactea* J, *Persoonia gunnii* AEG, *Pimelea sericea* AB, *Poranthera microphylla* K, *Prionotes cerinthoides* EG, *Pterygopappus lawrencii* KN, *Restio complanatus* LM, *Richea curtiseae* NO, *Rubus gunnianus* EGK, *Senecio leptocarpus* EG, *S. papillosus* BCK, *Stylidium graminifolium* AM, *Telopea truncata* A, *Tetracarpaea tasmanica* EG, *Trochocarpa gunnii* G, *Xyris marginata* M.



## DISCUSSION

The complete absence of *Eucalyptus* from the forest in the three sub-alpine valleys to the east, south-west and northwest of the Boomerang appears to have resulted from a combination of low fire frequency, barriers to successful regeneration in the periods between fires, and the lack of nearby seed sources of *Eucalyptus* populations able to compete in the sub-alpine forest.

Over most of the area of these valleys drainage is free, and stands of *Eucalyptus* species can be found elsewhere in southwest Tasmania on all of the rock types that occur in the valleys. Thus, edaphic factors are not responsible for eliminating *Eucalyptus*.

The shrub-sized *E. vernicosa* is able to regenerate above the tree-line without fire, particularly on the mudstone, where considerable areas of exposed mineral soil form a suitable seed bed. Although harsh climatic conditions must greatly lower the chances of successful regeneration, some young individuals had obviously established without fire. Below about 1000 m, the denser, taller vegetation produces a thick organic covering over the ground surface, and lowers the light intensity at ground level, so that *Eucalyptus* regeneration is virtually impossible without fire (Gilbert 1959, Mount 1969). Although some *E. vernicosa* seed from the alpine populations probably reaches the sub-alpine sites when fire has prepared a seed bed it appears that if any seedlings do establish, they die after being over-topped by the faster growing, taller rainforest species, since no *E. vernicosa* was found on the Boomerang at sites that had been burnt within the last century. One adult *E. vernicosa*, judged to be at least 200 years old, was found at an altitude of 850 m (near site A, Fig. 5), on the edge of a cliff where it had been able to avoid competition from the surrounding rainforest. Although reaching a height of 4 m, it had the small (2 cm) leaves characteristic of the alpine populations. At more fire-prone sites such as Mt. Arrow-smith, *E. vernicosa* extends downslope in taller shrub and tree-sized clime forms, with much larger leaves (Jackson 1960). It seems that average fire frequency in the Mt. Bobs area has been too low to allow the survival of such populations.

*Leptospermum nitidum*, which has a similar life cycle to the eucalypts, occurs in the Pine Lake-Lake Sydney subalpine valley. Most of the individuals are found on poorly drained sites, and are adults nearing the end of their life, but some regeneration has occurred on sites burnt within the last century. Occasional seedlings were found in open areas around the edge of the Pine Lake Moor, showing that the species could regenerate in open swampy areas in the absence of fire. It appears that such open, swampy areas, around Lake Sydney and the Pine Lake Moor, provide

sites for regeneration during the long periods without fire in which the species would otherwise die out like the eucalypts.

The minimum ages on the *Athrotaxis* in the tall open forest south of Pine Lake, together with the absence of any fire scarring in this forest, show that some of the valley has been unburnt for at least 500 years. However, fires have burnt a small area just to the north of Lake Sydney, and much of the Boomerang (see Fig. 4). The dates of these fires, judging from ring counts on *Athrotaxis* saplings, were about 1890 and 1930 (most probably 1934, a year of widespread fires in South-West Tasmania) respectively. Some other stands of scrub and forest around the two mountains have been burnt 200-300 years ago, judging from the presence of numerous dead trunks of fire-killed *Athrotaxis*, and the size of the regrowth.

After a fire, the following sequence is typical on well drained slopes. *Nothofagus cunninghamii* regenerates from coppice, and the other species regenerate from seed dispersed from unburnt areas. *N. cunninghamii*, *Eucryphia lucida*, *Bauera rubioides* and *Richea scoparia* dominate the regrowth for the first few decades. *A. selaginoides* establishes at densities that decrease from the edges of the burn. Over small (less than 1 km) burns the density is typically equivalent to very open woodland. Although this species appears to establish only after other species can act as a nurse crop, it has a faster growth rate once established, and after 2-3 centuries a structure of emergent *A. selaginoides* woodland over a closed scrubland or low forest of the other species develops. Some species present in the early stages of succession, such as *Bauera* and *Gahnia grandis*, are overtopped and eliminated. This stage is typical of most of the western slopes of the Boomerang (Plate 14).

In the tall open-forest south of Pine Lake, there is some evidence of a two-generation age structure for *Athrotaxis*, with occasional very large (greater than 1.5 m d.b.h.) individuals and a much higher density of narrow crowned individuals with d.b.h. of 0.4-1.2 m. This forest is undergoing a process of self-thinning, with 10-20% of the narrow-crowned *Athrotaxis*, and a similar proportion of the *Nothofagus* and *Atherosperma*, dead or dying. The basal area of the stand (219 m<sup>2</sup>/ha) is very high in comparison with the values obtained by Ogden and Powell (1979) for forests on the lower mountain slopes at Mt. Field. These workers obtained mean and maximum basal areas of 121.9 and 208.5 m<sup>2</sup>/ha for tall open eucalypt forest and mixed (eucalypt-rainforest) forest at altitudes up to 748 m, the corresponding figures for subalpine forests above this altitude being 38.6 and 76.3 m<sup>2</sup>/ha. Examination of the increment cores from the Pine Lake forest shows that the growth rates of most of the *Athrotaxis* has slowed



PLATE 13

*Richea pandanifolia* — *R. scoparia* low-shrubland, with *Astelia alpina* understorey, on sloping area, Mt. Bobs Plateau.



PLATE 14

Lake Sydney (foreground), Pine Lake and north west slope of the Boomerang, seen from Mt. Bobs. Fire boundaries are clearly visible.



dramatically over the last century, presumably because of the development of intense competition. On most trees there has been a diameter increment of less than 2 cm over the last 50 years, compared with a rate of 10-20 cm per century for most of their lives.

The structure of the Pine Lake forest suggests that there was a phase of heavy *Athrotaxis* recruitment between 500 and 400 years ago. At that time, there were already a few adults (perhaps established as a result of a past fire, and emergent at open woodland density over a rainforest canopy) and these trees probably were the seed source for the major recruitment phase. No seedlings or saplings of *Athrotaxis* were found, nor was there evidence of recruitment over the last 3 centuries. Ogden (1978) has found stands of *Athrotaxis* consisting of two or three generations, separated by quite wide gaps, at other Tasmanian sites. The factors responsible for controlling this phasic pattern of regeneration in *Athrotaxis* are not known. The absence of fire scars on the largest, oldest trees suggests that fire was not the factor enabling the self-thinning *Athrotaxis* age class to establish at Pine Lake. Fluctuations in seed supply are not responsible, as the species has at least one good seed year per decade, and produces seed in nearly all years (W. D. Jackson, pers. comm. 1978). It appears that low light intensity can also be rejected as the factor preventing present-day recruitment of *Athrotaxis*, since regeneration of *Nothofagus*, *Atherosperma* and *Phyllocladus* is occurring, and *Athrotaxis* seedlings and saplings have been observed by Harwood in the Cradle Mountain area, in forests that are just as dense as the Pine Lake forest.

The non-sorted steps of the Boomerang closely resemble the terraces on the eastern leeward slopes of Macquarie Island, described by Taylor (1955) except for the completely different floristic composition of their fjaeldmark vegetation. In both cases the treads are bare and the risers are fully vegetated, although at the latter site the vertical distance between the treads is greater (0.6 to 6 m). This difference can be ascribed to the greater overall slope of the terrain on which the steps are developed at Macquarie Island, since Taylor noted that the vertical distance between treads tended to increase with steepening of the topography. Steps of the type noted by Taylor on the western windward slopes, on which the treads are vegetated and the risers are bare, do not occur on the Boomerang. Costin *et al.* (1967) studied non-sorted steps near Mt. Kosciuszko in the Australian Alps. These differ from the steps at the Boomerang in a number of ways. They have a much smaller lateral extent, and are not regularly arranged on the slope. Individual steps are often lobed, in contrast to the uniform terraces following the contour lines at the Boomerang. In general, the Mt. Twynam steps are more fully vegetated, carrying fjaeldmark or develop-

ing herbfield on the treads as well as the risers.

Taylor suggested that the main factor responsible for the development of steps in fjaeldmark vegetation was strong wind, which so restricted plant growth that a continuous vegetation cover could not develop. He noted that on both the leeward and windward slopes of Macquarie Island, the vegetation was growing on that part of the step that was sheltered from the direct blast of the wind. Taylor suggested that the steps on lee slopes originate when soil creep builds up material on the uphill side of the few plants initially colonizing the bare slope, giving them more protection from the wind and enabling them to grow and accumulate more material. The small steps thus developed would eventually coalesce laterally to form extensive terraces, any height differences between laterally adjacent steps being eliminated by turbulence that would increase wind strength at the higher level, killing plants there, with subsequent redistribution of soil materials by soil creep. Taylor judged the terraces to be stable in position and shape, once formed. Costin *et al.* however, considered that the steps in the Mt. Kosciuszko area were formed initially by mass downslope movement, most probably initiated by impeded drainage brought about by deep freezing followed by differential thawing, in previous colder climates. The Mt. Kosciuszko steps, like those on the lee slopes of Macquarie Island, appear to be stable at present, apart from downward surface movement from the treads brought about primarily by the numerous freeze-thaw cycles.

The assessment of the relative importance of these two suggested modes of step origin at the Boomerang must await more detailed observations, including excavations. There appears to be no mass downslope movement at present, the risers being flat or concave in cross section, and there being no obvious downward distortion of root systems (cf. Costin *et al.* 1967). The mixture of small rock fragments and fine silt that results from the weathering of the mudstone is very unsuitable for plant growth, probably because of the low water holding capacity and lack of protection against frost heaving. Soils developed from dolerite, with similar exposure at the same altitude (for example, the western edge of the Mt. Bobs plateau) are usually fully vegetated, and non-sorted steps do not form. Active periglacial features are almost entirely confined to the mudstone in the study area, the exception being a few apparently active stone polygons in bare depressions on the Mt. Bobs plateau.

However, non-sorted steps, albeit less clearly developed, have been observed on a dolerite substrate on the western face of Mt. Rufus, at an altitude 300 m higher than that of the Boomerang.

Although quantitative soil analyses have not been undertaken, it is clear from general observations



that the characteristics of the various substrates in the area affect the species composition and structure of the vegetation in a number of ways. The most striking example is the refuge provided for forbs, ferns and grasses by the limestone cliffs south of Lake Sydney. Over most of the lower valley slopes the parent material is a mixture of more than one rock type, because of periglacial and glacial downslope movement. Near the summits, substrate effects can be more clearly discerned. Permian mudstone has the highest percentage of bare ground, and this appears to favour establishment of *Eucalyptus vernicosa*, which is most common on mudstone. No species was completely confined to the mudstone, however. The flat shelves of sandstone on and around the Boomerang are generally occupied by low closed-heath, whereas on steeper slopes at the same altitude scrub communities occur on all rock types. The horizontal bedding and lack of vertical jointing on the sandstone shelves has led to the development of shallow (usually less than 15 cm) peaty soil over solid bedrock, very prone to waterlogging. *Restio complanatus* is very common on these sandstone shelves, but restricted to them within the study area, and generally appears to be restricted to silica-rich sites (Kirkpatrick, unpublished data). The other 38 species confined to the Boomerang are not believed to be exclusive to sandstone and mudstone substrates in other Tasmanian mountains. However, of the alpine species confined to Mt. Bobs, *Pimelea sericea* and *Lagenophora stipitata* are generally limited in their distribution to base-rich substrates.

Mt. Bobs has fewer species of vascular plants above treeline than the Boomerang (77 compared with 106) despite its having a rather larger alpine area. This may be largely accounted for by its very uniform topography, with the resultant development of one plant community over almost all of the plateau surface.

Of the species observed above the treeline on Mt. Bobs, 58% are Tasmanian endemics, the corresponding figures for the Boomerang and the adjacent forest and closed-scrub communities being 57%. These figures are high when compared with the 33% of Tasmanian endemics out of the 110 species found above treeline at Mt. Wellington (Ratkowsky & Ratkowsky 1976).

The alpine floras of Mt. Bobs and the Boomerang more closely resemble those of Mt. Field (Davies 1978) with which they respectively share 64 and 83 of its 140 species, than Mt. Wellington with which they respectively share 27 and 36 species. Mt. Wellington receives only 1400 mm of precipitation per annum and its alpine vegetation includes a 'dry element' and many native and exotic adventives absent from the other mountains. The Mt. Bobs-Boomerang flora does not include any exotic species. The rela-

tively large number of species found in alpine vegetation at Mt. Field may be a reflection of the larger (12 km<sup>2</sup>) area above the treeline (Fig. 1). Mt. Bobs and the Boomerang share similar numbers of species with the West Coast Range (Kirkpatrick 1977), the Eastern Arthur Range (Kirkpatrick, unpublished data) and Mt. Picton (Kirkpatrick, unpublished data) as they do with Mt. Field. These mountains consist largely of highly siliceous rocks, in contrast to the dolerite of Mt. Field and Mt. Wellington, but are within the zone of very high precipitation with annual totals probably exceeding 2000 mm in all cases. These comparisons suggest that climate may play a greater role in the floristic differentiation of Tasmanian alpine vegetation than substrate differences.

The alpine vegetation of Mt. Bobs and the Boomerang exhibits three features previously undescribed from Tasmania. These features are:

1. The non-sorted steps of the Boomerang.
2. The snow patch herbland of the Boomerang.

The *Milligania densiflora*-*Astelia alpina* association has been observed by Kirkpatrick at Walled Mountain and the Eastern Arthur Ranges at sites where snow would tend to persist, but at neither of these localities is there the striking development evident on the Boomerang.

3. The open depressions on the Mt. Bobs plateau. The degree of dominance of the bolster plants in the *Donatia novae-zelandiae*-*Oreobolus pumilio* low closed-heath on Mt. Bobs, and the large area that it covers, make it probably the best example of this community in Tasmania, to which it is restricted. It is found however at other locations, including Mt. Field and the Eastern Arthur Range.

The study area as a whole is unusual for its generally low incidence of fire. This may have been a factor in favouring development of communities dominated by endemic species, and those with New Zealand and South American affinities, at the expense of the Australian element of the Tasmanian mountain flora.

The maintenance of the present vegetation depends on avoiding an increase in the frequency of fire. Small areas burnt by spot fires, such as that near the sinkhole, regain their pre-burn floristic composition relatively quickly. The recovery of *Athrotaxis* and other fire-susceptible species after larger burns such as that on the northern arm of the Boomerang is a process of centuries of marginal invasion from the edges of the burn, and, once these reach reproductive age, spread from occasional individuals established from propagules dispersing more than the usual few metres. The danger of 'ecological drift' (Jackson 1968) towards a



more inflammable vegetation, thus increasing the likelihood of further fires, may be considered after an extensive fire. For example, the fire risk at site 5, burnt about 50 years ago (Fig. 5) appears greater than that at the adjacent site 4 (unburnt for centuries) because of the lower, more broken canopy allowing greater drying of fuels in hot weather, and the presence of greater amounts of inflammable understorey fuels such as those provided by the sedge *Gahnia grandis*.

A fire that burnt most or all of the area, as has occurred in historical times for other Tasmanian mountains, might effect extremely long term changes in the composition of its vegetation. In particular, the gymnosperm species and *Nothofagus gunnii* would be eliminated until long-distance dispersal returned them to the area. Thus, the risk of increased fire frequency referred to in the introduction has serious implications.

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## APPENDIX

SPECIES OBSERVED IN THE MOUNT BOBS-BOOMERANG-LAKE SYDNEY-PINE LAKE AREA  
DECEMBER 1976 (T. MOSCAL) AND DECEMBER 1977 (J. KIRKPATRICK & C. HARWOOD)

	Family	Life form	BB	B0	Locality*			LC
					M	F		
<i>Abrotanella forsterioides</i> Cass.	Compositae	shrub	x	x				
<i>Abrotanella scapigera</i> F. Muell.	"	shrub	x	x				
<i>Acaena montana</i> Kirk.	Rosaceae	herb		x				
<i>Acaena novae-zelandiae</i> Hook. f.	"	herb						x
<i>Actinotus suffocata</i> (Hook. f.) Rodw.	Umbelliferae	herb	x	x	x			
<i>Actinotus moorei</i> Rodw.	"	herb	x		x			
<i>Agastachys odorata</i> R. Br.	Proteaceae	shrub	x	x		x		
<i>Agrostis billardieri</i> var. <i>filifolia</i> J.W. Vickery	Gramineae	herb						x
<i>Anodopetalum biglandulosum</i> A. Cunn. ex. Hook. f.	Cunoniaceae	shrub				x		
<i>Anopterus glandulosus</i> Labill.	Escalloniaceae	shrub				x		
+ <i>Apteroptheris malingii</i> (Hook.) Cop.	Hymenophyllaceae	fern				x		
<i>Archeria eriocarpa</i> Hook. f.	Epacridaceae	shrub				x		x
<i>Archeria hirtella</i> (Hook. f.) Hook. f.	"	shrub				x		
<i>Archeria serpyllifolia</i> Hook. f.	"	shrub	x	x		x		
+ <i>Aristotelia peduncularis</i> (Labill.) Hook. f.	Elaeocarpaceae	shrub		x		x		
<i>Asplenium bulbiferum</i> Forst. f.	Aspleniaceae	fern		x				x
<i>Asplenium flabellifolium</i> Cav.	"	fern						x
<i>Astelia alpina</i> R. Br.	Liliaceae	herb	x	x	x	x		
<i>Atherosperma moschatum</i> Labill.	Monimiaceae	tree				x		
<i>Athrotaxis selaginoides</i> D. Don.	Taxodiaceae	tree, shrub	x	x	x	x		



## APPENDIX (continued)

	BB	BO	M	F	LC
<i>Australina pusilla</i> Gaud.					
<i>Bauera rubioides</i> Andr.					
<i>Bellendena montana</i> R. Br.	x	x	x	x	x
<i>Blandfordia punicea</i> Sweet.	x	x			x
<i>Blechnum chambersii</i> Tindale	x	x			
<i>Blechnum fluviatile</i> (R. Br.) E.J. Lowe ex. Salomon					x
<i>Blechnum minus</i> (R. Br.) Ettingsh.		x			x
<i>Blechnum penna-marina</i> (Poir) Kuhn					
<i>Blechnum vulcanicum</i> (Blume) Kuhn				x	x
<i>Blechnum wattsi</i> Tindale					
<i>Calorophus elongatus</i> Lab.					
<i>Calorophus lateriflorus</i> (R. Br.) F. Muell.	x	x	x	x	x
<i>Cardamine</i> sp.					
<i>Carex breviculmis</i> R. Br.					x
<i>Carex gaudichaudiana</i> Kunth.					x
<i>Carpha alpina</i> R. Br.	x	x	x		
<i>Celmisia longifolia</i> Cass.	x				
<i>Celmisia saxifraga</i> Comber	x	x	x		
<i>Cenarrhenes nitida</i> Labill.		x			
<i>Centrolepis monogyna</i> Benth.	x	x		x	
+ <i>Chiloglottis cornuta</i> Hook. f.					x
+ <i>Chiloglottis gunnii</i> Lindl.					
<i>Coprosma moorei</i> Rodw.					
<i>Coprosma nitida</i> Hook. f.		x	x		
<i>Cyathodes dealbata</i> R. Br.	x	x			
<i>Cyathodes juniperina</i> (Forst.) Druce	x	x			x
Urticaceae					herb
Cunoniaceae					shrub
Proteaceae					shrub
Liliaceae					herb
Blechnaceae					fern
"					fern
"					fern
"					fern
"					fern
"					fern
Restionaceae					herb
"					herb
Cruciferae					herb
Cyperaceae					herb
"					herb
"					herb
Compositae					herb
"					herb
Proteaceae					shrub
Centrolepidaceae					herb
Orchidaceae					herb
"					herb
Rubiaceae					shrub
"					shrub
Epacridaceae					shrub
"					shrub

## APPENDIX (continued)

	BB	BO	M	F	LC
<i>Cyathodes parvifolia</i> R. Br.	x	x		x	
<i>Danthonia</i> sp.	x	x			
<i>Danthonia purpurescens</i> J.W. Vickery					x
<i>Dichosciadium ranunculaceum</i> (F. Muell.) Domin.		x			
<i>Diplarrhena latifolia</i> Benth.	x	x		x	
<i>Diselma archeri</i> Hook. f.	x	x			
<i>Diplaspis cordifolia</i> Hook. f.	x	x			
<i>Donatia novae-zelandiae</i> J.R. & G. Forst.	x	x			
<i>Dracophyllum milligani</i> Hook. f.	x	x		x	
<i>Dracophyllum minimum</i> F. Muell.	x	x			
<i>Drimys lanceolata</i> (Poir.) Baill.	x	x		x	
<i>Drosera arcturi</i> Hook.	x	x	x		
<i>Epacris serpyllifolia</i> R. Br.	x	x	x	x	
<i>Epilobium</i> sp.					x
<i>Erigeron stellatus</i> (Hook. f.) W.M. Curtis	x	x			
<i>Eucalyptus vermicosa</i> Hook. f.	x	x			
<i>Eucryphia lucida</i> (Labill.) Baill.					
<i>Eucryphia milligani</i> Hook. f.	x	x		x	
<i>Euphrasia hookeri</i> Wettst.	x	x			
<i>Euphrasia striata</i> R. Br.					
<i>Ewartia meredithae</i> (F. Muell.) Beauv.	x	x		x	
<i>Ewartia planchonii</i> (Hook. f.) Beauv.	x	x			
<i>Exocarpos humifusus</i> R. Br.		x	x		
<i>Forstera bellidifolia</i> Hook. f.		x			
<i>Gahnia grandis</i> Hook. f.	x	x	x		
<i>Gaimardia setacea</i> Hook. f.	x	x	x		
Epacridaceae					
Gramineae					
"					
Umbelliferae					
Iridaceae					
Cupressaceae					
Umbelliferae					
Donatiaceae					
Epacridaceae					
"					
Winteraceae					
Droseraceae					
Epacridaceae					
Onagraceae					
Compositae					
Myrtaceae					
Eucryphiaceae					
"					
Scrophulariaceae					
"					
Compositae					
"					
Santalaceae					
Stylidiaceae					
Cyperaceae					



## APPENDIX (continued)

	BB	BO	M	F	LC
<i>Galium</i> sp.					x
<i>Gaultheria hispida</i> R. Br.		x			
<i>Gentianaella diemensis</i> J.H. Willis		x			
<i>Geranium potentilloides</i> L'Herit. ex DC.					x
<i>Geum talbotianum</i> W.M. Curtis		x			
<i>Gleichenia abscida</i> Rodw.				x	
<i>Gleichenia alpina</i> R. Br.	x	x	x		
<i>Gnaphalium</i> sp. 1					x
<i>Gnaphalium</i> sp. 2					x
<i>Grammitis billardieri</i> Willd.				x	
<i>Grammitis armstrongii</i> Tindale					
<i>Halonagis montana</i> Hook. f.	x	x			
<i>Helichrysum backhousii</i> (Hook. f.) F. Muell. ex Benth.	x	x			
<i>Helichrysum milliganii</i> Hook. f.	x	x			
<i>Helichrysum purpureum</i> Hook. f.	x	x			
<i>Hierochloa fraseri</i> Hook.				x	
<i>Histiopteris incisa</i> (Thunb.) J. Sm.					x
<i>Hydrocotyle muscosa</i> R. Br.					x
<i>Isophysis tasmanica</i> (Hook.) T. Moore	x	x	x		
<i>Juncus subsecundus</i> N.A. Wakefield					x
<i>Lagenophora stipitata</i> (Labill.) Druce	x				
<i>Leptospermum nitidum</i> Hook. f.	x	x			x
<i>Lomatia polymorpha</i> R. Br.	x				x
<i>Lycopodium fastigiatum</i> R. Br.	x	x			
<i>Lycopodium scariosum</i> Forst. f.		x			x

APPENDIX (continued)

	BB	BO	M	F	LC
<i>Lycopodium selago</i> L.		x			
<i>Microcachrys tetragona</i> (Hook.) Hook. f.	x	x	x		
<i>Microlaena tasmanica</i> H.	x	x	x		
<i>Microsorium diversifolium</i> (Willd.) Copeland					x
+ <i>Microstrobus niphophilus</i> Gardén & Johnson			x		
<i>Milligania densiflora</i> Hook.	x	x			
<i>Mitrasacme archeri</i> Hook. f.	x	x			
<i>Mitrasacme montana</i> Hook. f.	x	x	x		
<i>Monotoca submutica</i> Jarman	x	x		x	
<i>Myriophyllum elatinooides</i> Gaudich.					
<i>Nothofagus cunninghamii</i> (Hook.) Oerst.	x	x			
<i>Nothofagus gunnii</i> (Hook. f.) Oerst.	x	x	x	x	x
<i>Olearia ledifolia</i> (DC.) Benth.	x	x			
<i>Olearia persoonioides</i> (DC.) Benth.		x		x	
<i>Olearia phlogopappa</i> (Labiell.) DC.					
<i>Olearia piniifolia</i> (Hook. f.) Benth.	x	x			
<i>Oreobolus acutifolius</i> S.T. Blake		x		x	
<i>Oreobolus pumilio</i> R. Br.		x	x		
<i>Orites acicularis</i> R. Br.	x	x			
<i>Orites diversifolia</i> R. Br.	x	x		x	x
<i>Orites revoluta</i> R. Br.	x	x			
+ <i>Oreomyrrhis ciliata</i> Hook. f.		x			
<i>Ourisia integrifolia</i> R. Br.		x			
<i>Oxalis lactea</i> Hook.		x		x	
<i>Pentachondra pumila</i> (Forst.) R.Br.	x	x	x		
<i>Persoonia gunnii</i> Hook. f.		x		x	





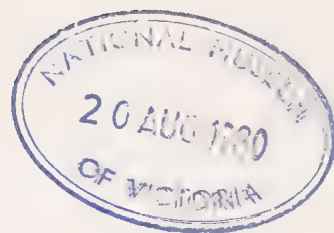
## APPENDIX (continued)

	BB	BO	M	F	LC
<i>Senecio leptocarpus</i> DC.	x				
<i>Senecio papillosum</i> F. Muell.	x	x			
<i>Senecio pectinatus</i> DC.	x	x			
<i>Sprengelia incarnata</i> Sm.	x	x	x	x	
<i>Stylidium graminifolium</i> Swartz	x	x	x		
<i>Telopea truncata</i> (Labill.) R. Br.	x			x	
<i>Tetracarpaea tasmanica</i> Hood. f.		x		x	
+ <i>Townsonia viridis</i> (Hook. f.) Schlechter					
<i>Trochocarpa cunninghamii</i> (D.C.) W.M. Curtis	x	x		x	
<i>Trochocarpa gurnii</i> (Hook. f.) Benth.		x		x	x
<i>Uncinia compacta</i> R. Br.	x	x		x	
<i>Uncinia tenella</i> R. Br.				x	
<i>Veronica calycina</i> R. Br.		x			
<i>Viola hederacea</i> Labill.					x
<i>Xyris marginata</i> Rendle		x			
TOTAL	77	106	30	55	33

\* BB = Alpine vegetation, Mt. Bobs; BO = Alpine vegetation, the Boomerang; M = Heath and herbland between Pine Lake and Lake Sydney; F = Forest and scrub; LC = Growing on exposed limestone in the sinkhole or on cliffs along the southern edge of Lake Sydney; + = seen only by T. Moscal.







## SOIL STRATIGRAPHY IN THE MURRAY VALLEY AT ALBURY-WODONGA: A NEW APPROACH TO SURFICIAL STRATIGRAPHY

By D. C. VAN DIJK\* AND R. K. ROWE†

**ABSTRACT:** The valleys of the Murray River and its tributaries at their debouchments from the mountain ranges consist of multistep landscapes which include alluvial terraces, flights of alluvial or colluvial fans, and residual ridges or spurs and hills with several concordant upper levels.

A soil-stratigraphic study of types of soil-profile development and geomorphic relationships led to the recognition of fourteen soil-geomorphic units which have been named 'pedo-morpholiths'

For the separation of the soils of different ages, a special study of deep-seated pedogenetic features below the sola was needed because of difficulties in using the sola alone.

The study was originally confined to the valley lowlands but was extended and correlated with denudational landforms of the higher valley sides, where a sequence of valley pediments and basin-shaped, dell-like valleys were found to be related to the older units of the alluvial sequence.

Three main periods of geomorphic development have been recognised. The characteristics of the oldest development are broad, 3-7 km wide, trough-shaped valleys, and smooth, well-rounded topographic highs which grade with long gentle footslopes to the valley floors. Deep weathering zones, 70-130 m thick, commonly with heavy clay layers, are found in these localities, and lateritic weathering patterns are often exposed along the margins of these valley remnants. Two pedo-morpholiths have been related to this period.

The second period of landscape development involved four pedo-morpholiths. Major valley steps were shaped by valley dissection in which there were two different major processes: firstly narrow, deep, stream incision, and secondly broad landscape degradation leading to pediment-like forms and basin-shaped valleys or dells. Extensive hillslope colluvia, pedisements, and thick valley fills were deposited. The two older pedo-morpholiths of this period are characterised by clayey red earths and krasnozems and in places show lateritic weathering patterns. The next younger pedo-morpholith is dominated by deep, dark grey-brown clays, and the youngest pedo-morpholith shows a unique two-storey B-horizon which provides a reliable soil-stratigraphic marker.

The development of the third geomorphic period involved eight pedo-morpholiths which mainly affected the central low belts of the valleys and resulted in terraced alluvia and smaller stepped colluvial fans.

### INTRODUCTION

A tentative interpretation of the soil stratigraphy in a number of tributary catchments of the upper Murray Valley in Victoria (Rowe 1967, and unpublished data) revealed a number of problems in both interpretation and correlation of layered soils. Studies of features resulting from deep-seated pedogenesis in palaeosols on the adjacent Tablelands to the northeast in New South Wales (van Dijk 1969, and unpublished data) were found to be useful in clarifying such problems.

A joint study of soil-stratigraphic relationships was initiated in the Wodonga district of Victoria, at the

debouchment of the upper Murray stream system onto the Riverine Plain (Figs. 1 & 2) with the objective of elucidating the basic soil-stratigraphic sequence, so that prediction might be made about the soil pattern through the region.

The landscape of the study area is characterized by a pattern of broad valley plains (Fig. 3) between stepped ridges and low hills; typical cross-sections are illustrated in Fig. 4. Extensive, thick mantles of transported material which was deposited in these valleys show an abundance of distinct sequences of soil layers. There are extensive, well-separated alluvial terraces along the streams, and the higher flanks of the valleys

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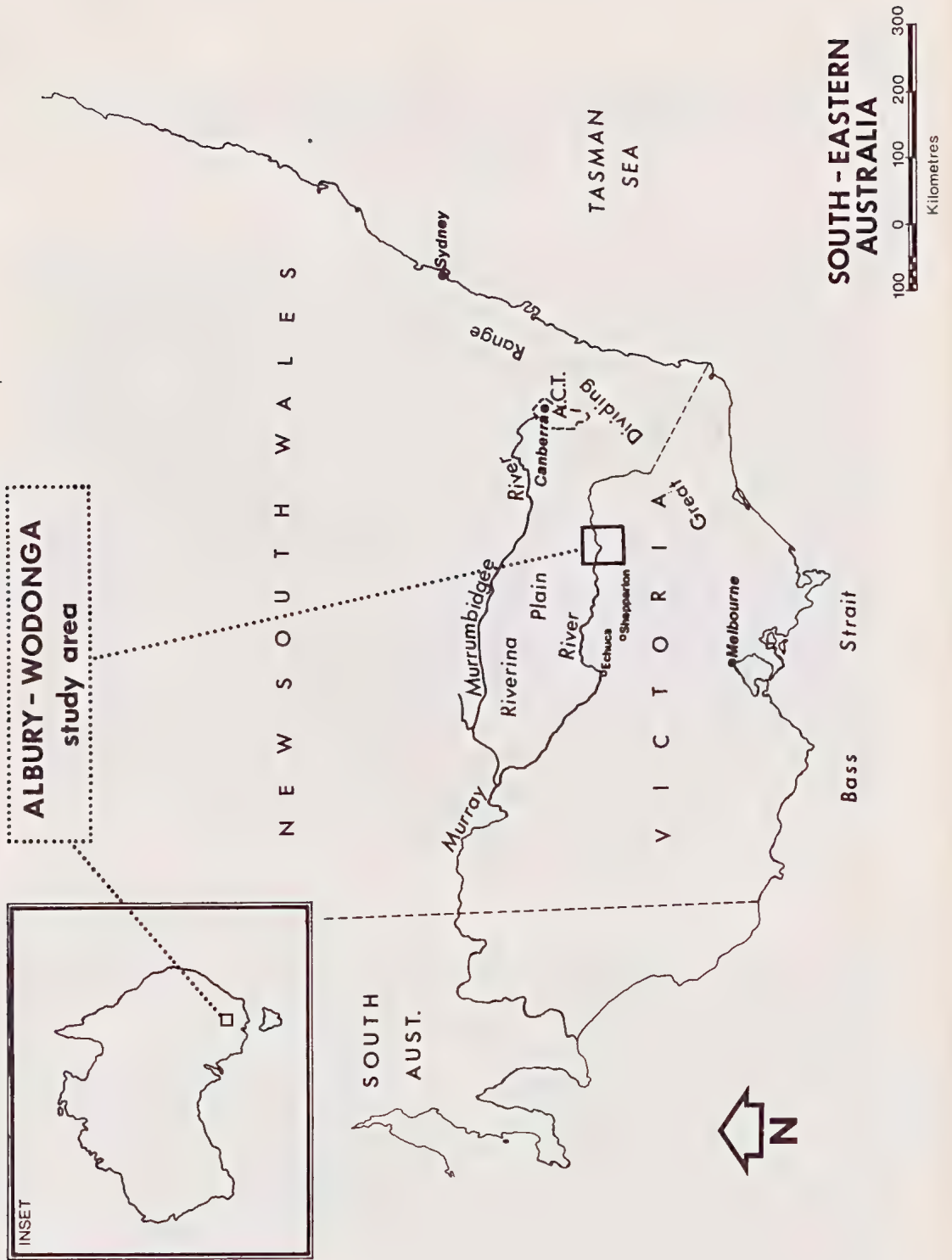


Fig. 1. Location of the study area.

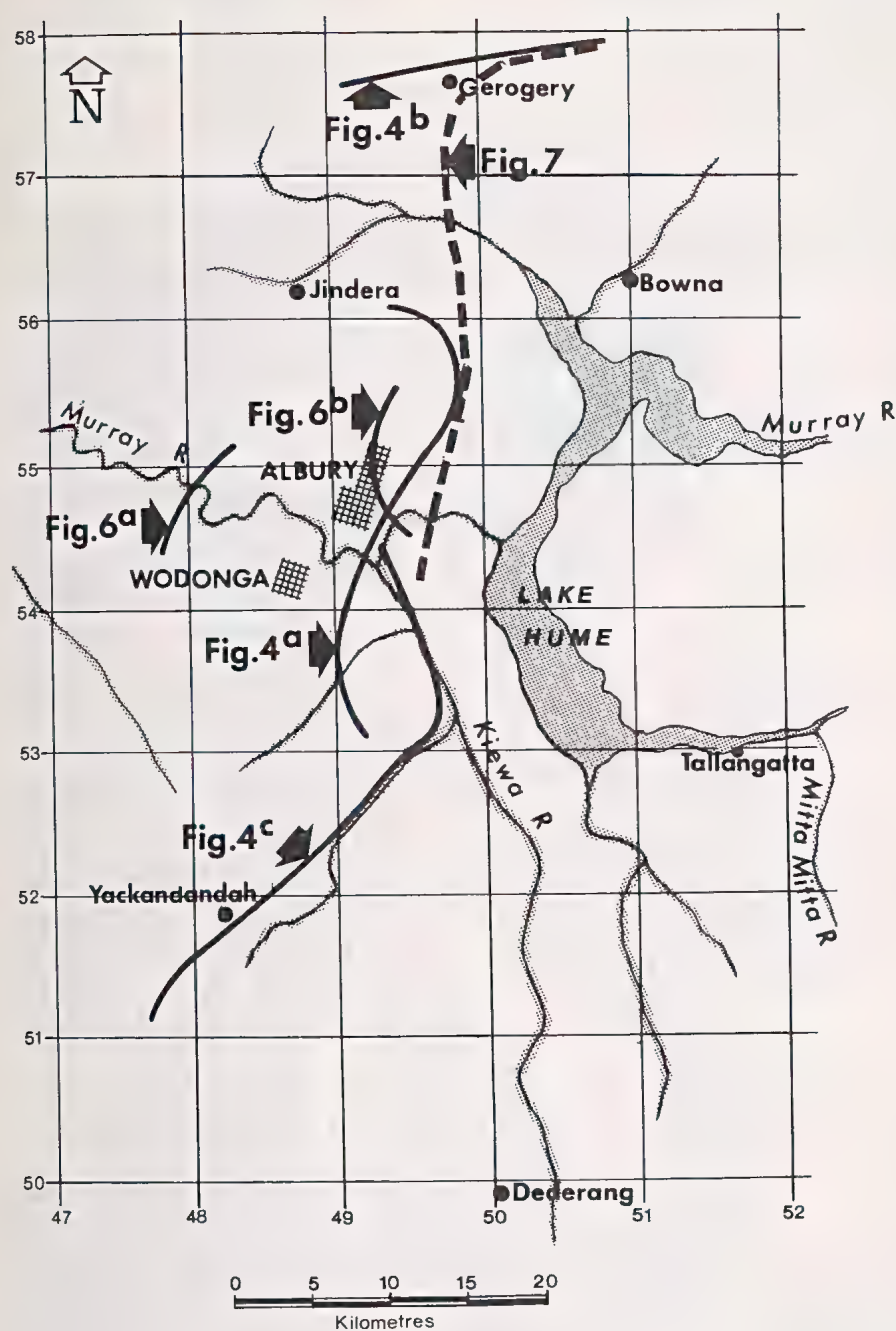


Fig. 2—Location of the sections of Figs. 4, 6 and 7. (The reference grid is taken from the topographic maps 1:250,000.)



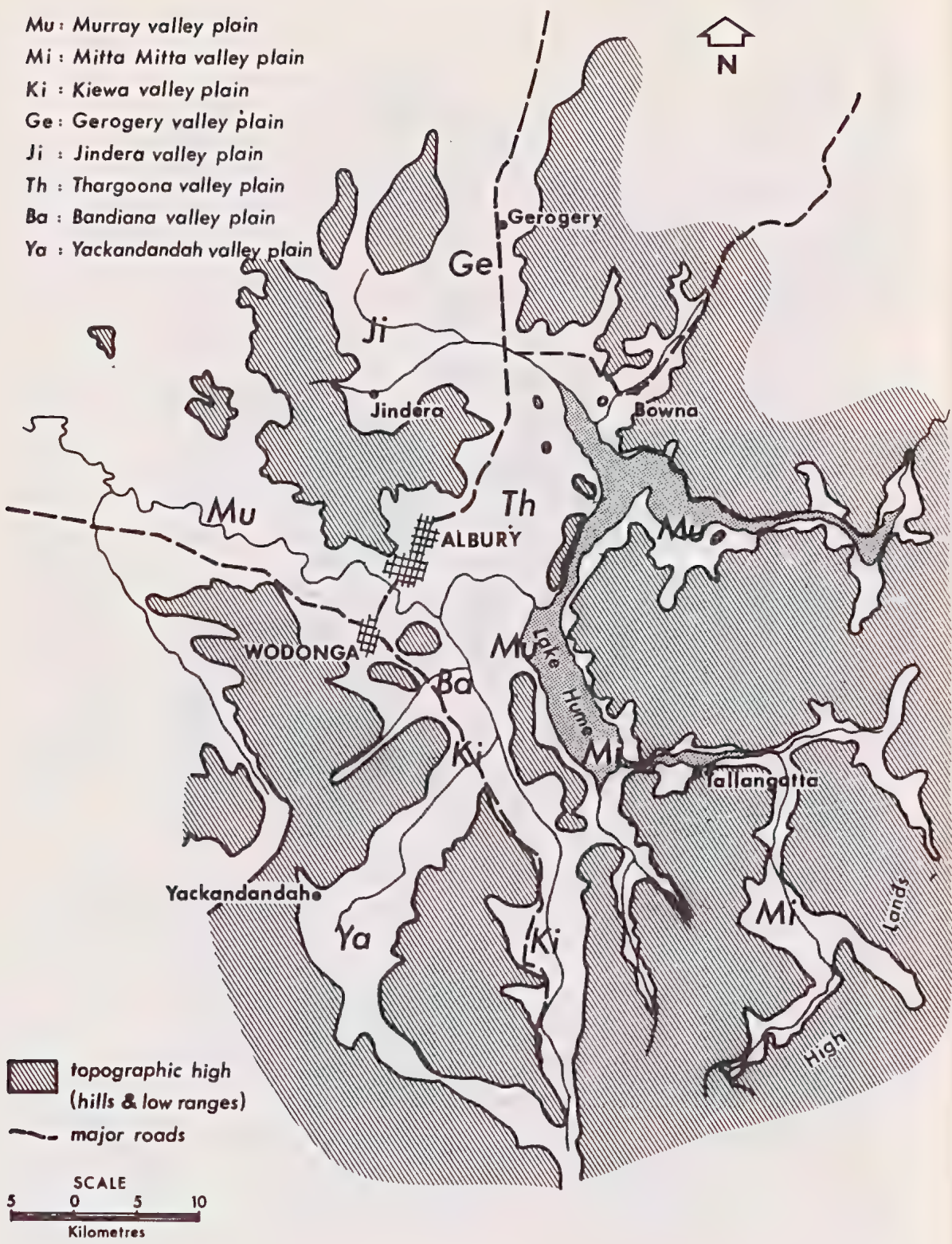


Fig. 3—Pattern of valley plains and topographic highs in the Albury-Wodonga region.

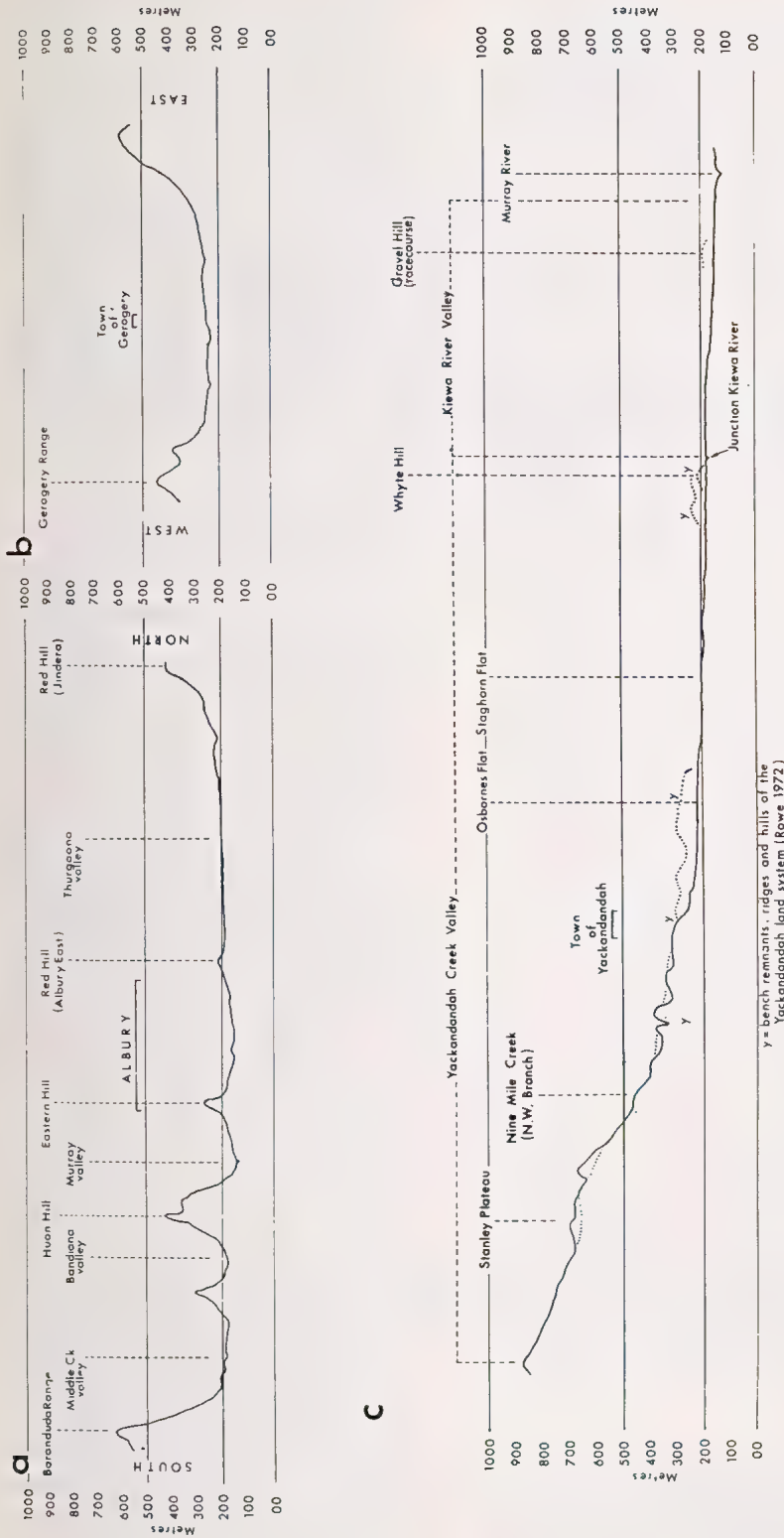


Fig. 4—Sections illustrating the general valley physiography in the Albury-Wodonga region. (The locations of the sections are shown in Fig. 2.)



are lined with multi-layered colluvial deposits and impressive fan-in-fan formations.

The region is also valuable because it presents a direct link for soil-stratigraphic correlations along continuous major valley formations between the highland valleys and the Riverine Plain where much is known about soil-age relationships (see Butler 1959, 1967, Lawrence 1966, van Dijk 1978).

## BASIC PRINCIPLES IN THIS STUDY

The following principles underlie our approach in this soil-stratigraphic study:

### 1. THE PEDO-MORPHOLITH CONCEPT

(i) *Definition*: The basic soil-stratigraphic unit used in this study is the 'pedo-morpholith'.<sup>1</sup> The term was originally introduced as a basic provisional unit in the description and correlation of sequences of colluvial and alluvial soil layers where surface form of the depositional body is an important correlation criterion (van Dijk *et al.* 1968).

A pedo-morpholith is composed of alluvial or colluvial material or, as commonly occurs, combinations of both. It is identified by (1) *specific surface soil and deeper-seated weathering patterns*; (2) *the nature of the sediment*; and (3) *a characteristic limited range of landscape forms* with the relative scale and proportion related to the local environment. (See also later p. 115 *et seq.*)

Ruhe (1956) introduced the term 'geomorphic surface' as a formal unit in soil-stratigraphic studies in which particular attention is paid to surface form. The use of that term in the present study does not seem appropriate because of its restricted meaning.

(ii) *The Problem of Periodicity*: A set of fourteen different pedo-morpholiths was recognised in the present study. This set has been interpreted as being related to an age-sequence by virtue of the stratigraphic relationships and contrasts in weathering of the units.

At this stage no formal claims are made with respect to the causes of the apparent periodicity in development and for this reason, the term 'groundsurface', the unit hitherto employed in soil-stratigraphic studies in adjacent regions (Butler 1967) has not been adopted, although the present study is in fact an extension of the groundsurface approach. The groundsurface is strictly a time rock-unit, and besides this, refers specifically to developments related to climatic

periodicity. The development of a time-stratigraphic sequence will depend on further field investigations of wider geographical extent.

The introduction of the pedo-morpholith as a provisional regional soil-stratigraphic unit permits the development of systematic studies of periodic phenomena in soil mantles through a series of successive approximations, with the pedo-morpholith sequence providing an informal framework for displaying regional soil-layer relationships as knowledge accumulates. This facilitates early publication of available soil-stratigraphic information without the need to meet the strict requirements of formal stratigraphic procedure. The definition of formal soil-stratigraphic units may then proceed, using the proposed term pedoderm (Brewer *et al.* 1970) when further detailed local studies have validated the general pedo-morpholith framework.

### 2. CRITERIA USED FOR IDENTIFICATION AND CORRELATION OF PEDO-MORPHOLITHS

The main criteria for the identification of the pedo-morpholiths are (i) pedological, (ii) sedimentary, and (iii) morphology characteristics. These may be given different emphasis during field studies; for instance, pedogenetic features play the major role in interpreting soil exposures, sedimentary features in establishing local continuities, and morphology in rapid broad-scale correlations such as the study of relationships to drainage basin topography.

(i) *Pedological Criteria*: A particular characteristic of this study was the intensive use made of deep-seated pedogenetic features. Using the characteristics of the upper A-B horizonation of the soil profile only, i.e. the solum,<sup>2</sup> to a depth of 1.5 m which is the traditional basis for classifying soils, presented great difficulties for stratigraphic correlation.

The deep-seated features occur extensively in the district and are particularly well developed in moderately low topographic sites. Most seem to be related to restricted drainage conditions and seepages (van

<sup>1</sup>The term pedo-morpholith is derived from two terms from the literature of stratigraphy: (1) the term morpho-stratigraphic unit, introduced by Frye and William (1962), and (2) the term pedolith proposed by Crook and Coventry (1967).

<sup>2</sup>The term 'solum' has been used in a limited sense. According to common practice the solum includes both A and B horizons to the total depth of observable pedogenetic alteration of the parent material, but in the present study a maximum depth limit of about 150 cm has been adopted. The soil profile features down to this depth are chiefly determined by environmental surface influences and biological activity, and below this depth the features are more related to specific deep-seated weathering and subsurface water regime. This depth limit is generally indicated by a more or less abrupt change in overall character of the soil and may be marked by a more or less bleached zone as shown in profiles AW4 and 8 of Fig. 5 which testifies the pedogenetic significance of the boundary.



Dijk 1969). They therefore have minimal development in the better-drained upslope situations, and grade to non-specific general types of hydromorphic differentiations at the lowest and wettest sites. Each pedo-morpholith has its own specific range of deep-seated features which facilitate recognition and correlation (see Fig. 5).

This method of soil-layer correlation, using the criteria of the deeper profile features, is in contrast to the practice followed elsewhere in which only the upper soil profile of the weathering mantle is employed. Morrison (1965) regards the deeper zones of weathering as being less diagnostic than the upper part of the soil profile. This difference in viewpoint is probably due to the different environments of the areas examined. The deep-seated features of soils in the present study area seem, for the most part, to result from particular soil drainage conditions, which have been controlled by the specific topographic, climatic and overall soil-mantle conditions. These almost certainly differ markedly from those in North America examined by Morrison.

(ii) *Sedimentary Criteria*: Sedimentary stratification can provide valuable evidence for establishing local continuities within pedo-morpholiths and particularly in verifying merging contacts. However, sedimentary criteria are generally less useful in identifying and correlating the pedo-morpholiths. This is because of the general lack of consistent differences between successive pedo-morpholiths, great complexities in the local stratification and, in older pedo-morpholiths, the masking of detailed characteristics by intensive clay-forming. For instance, the dense heavy clays of the Baranduda pedo-morpholith (AW9, Fig. 5) are not as uniform in texture as their frequently featureless appearance suggests.

(iii) *Morphology Criteria*: Morphology as a main criterion in the correlation of erosional-depositional developments is used for both detailed and broad-scale developments.

Depositional land forms may contain easily recognizable features such as terraces and fans varying in shape, size, and gradient, but there are also less obvious form contrasts which may be significant. Here we would cite differences in scale. For example a remnant of the alluvium of one pedo-morpholith may consistently be present as a narrow bench, barely separated vertically from the valley floor, whereas in another it may have the form of a broad terrace elevated many tens of metres above the present flood-plain. Similarly, when considering alluvial-colluvial fans, small fans covering only a few square metres may be typical of a particular pedo-morpholith but another may, under similar climatic conditions, form extensive deposits many hectares in extent. Moreover, colluvial

hillslope deposits may form only thin veneers, in which case they are difficult to identify as a component of a pedo-morpholith distinct from the underlying material, or they may be several metres thick and show independent morphology.

Although the larger pedo-morpholiths may often be shown to be older, local variations in form and position in the landscape need not follow this trend and small remnants of older units may be found as inclusions within younger units of larger dimensions.

Erosional land forms have been found to contain important criteria, particularly for recognizing landscape sculpture associated with the older pedo-morpholiths. These land forms consist of pediment-like surfaces and basin-shaped valley plains of varying size and shape which are apparently the result of vigorous surface wash processes. For the smaller basin-shaped valley plains the term 'dell'<sup>3</sup> is proposed while the larger forms are similar to the 'Pediplain Basins' of van Dijk (1959) and van Dijk and Woodyer (1961).

The discussions of land form criteria in the present paper have been limited to general aspects and a more detailed, specific account will be presented separately.

## THE PEDO-MORPHOLITHS

### 1. INTRODUCTION

The pedo-morpholiths are described in the order of increasing age. Principal pedogenetic differentiations between them are illustrated in Fig. 5. The soil profile characteristics shown in this figure represent developments which have occurred at low slope sites in the moderately well-drained class<sup>4</sup> and in moderately acidic parent materials. These are the conditions which apply to the most frequently observed field exposures in this area. The parent materials consist of the weathering products, either sedentary or mixed transported materials, from Palaeozoic sediments and granites, and from Tertiary sediments (Butler *et al.* 1973).

The soil profiles show marked differences in hydromorphic features despite the fact that they occur in approximately similar present soil drainage situations. This is seen mainly as a reflection of the markedly different climatic conditions under which the soils of different pedo-morpholiths developed in the past, and it is proposed to introduce the term 'hydro-

<sup>3</sup> A dell is a small dry valley with a shallow, dish-like cross-section; the term was originally used for dry valleys associated with a specific periglacial climate condition (Fairbridge 1968). The term has also been used for small dry valleys in general, irrespective of origin (Sharpe 1941).

<sup>4</sup> According to the soil drainage classification in Soil Survey Staff (1951).



TABLE I  
THE SEQUENCE OF PEDO-MORPHOLITHS IN THE ALBURY-WODONGA REGION

Geomorphogenetic grouping	Pedo-morpholith		Observed Main Occurrences of Pedo-morpholiths	
	Symbol and numbers	Name	(1) In the low relief of the central part of the valleys	(2) On the slopes of land of moderate relief on the sides and upstream portions of the valleys
I	I-a	0	Minor terraced sheets and cut-and-fill insets on the lower plains of the major stream valleys	Thin sheets on lower parts of steep slopes; deeper sheets locally on dell-shaped lower slopes
		1		
		2	Ferndale	
		3	Noorongong	
	I-b	4	Boorgunyah	
		5	Barnawartha	
		6	Kergunyah	
II		7	Mullagong	Extensive blankets on low- and mid-slopes  Deep-seated substratum on lower dell-shaped slopes at the foot of higher hills
	II-a	8	High terrace benches along the major stream valleys; broad low-angle fans, and sloping plains at the flaring outlet of side valleys	
		9	Mudgegonga	
			Baranduda	
	II-b	10	Isolated residuals of valley alluvium as spurs, low hills, small bench-remnants, and fills of small coves on the sides of valleys	
		11	Gundowring	
			Yackandandah	
III		12	Tallangatta	Sedentary and colluvial soils on higher margins and upstream sections of the valleys  Sedentary and some colluvial soils on high margins of broad valleys
		13	Stanley	
			Very deep weathering, particularly at the heads of valleys and on major broad cols	

morphic reach' to describe these differences. Hydromorphic reach is intended to give an indication of the proportion of a normal slope section occupied by soils with hydromorphic features such as grey colours, high plasticity of the clay and sesquioxidic segregation throughout the soil mass. Four classes have been used as indicated in the diagram in the upper right corner of Fig. 5. In class 0 hydromorphic development is restricted to the near-level foot of a slope; in class 1 it extends from the foot onto the lower slope section; in class 2 onto the middle slope section, and in class 3 well onto the upper slope.

## 2. DESCRIPTIONS

The following descriptions present only the readily observable gross pedogenetic characteristics. They should be read in conjunction with Table 1. More detailed soil characterization will be given in a separate publication.

(i) The pedo-morpholiths of Group I occur mainly on the lower floors of the valleys of the major streams and tributaries.

*Sub-group I-a.* The four units of this sub-group Dorchap (AW0) (506524),<sup>5</sup> (AW1) (498502), Ferndale (AW2) (497544), and Noorongong (AW3) (495539), are the dominant components of the soil mantle of the lower plains of the major stream valleys which were mapped as the Coonambidgal Formation by Brumley *et al.* (1974). Their pattern is generally very complex, but clearly separated and well exposed units were observed near the junction of the Kiewa and Murray Rivers and in the lower Mitta Mitta Valley. There are related small localised bodies of colluvium in fills of ravines and as shallow sheets on dell-shaped lower slopes at the base of steep slopes. The soil-profiles show a minimal to medial degree of solum differentiation. A soil profile on the Ferndale pedo-morpholith near the junction of the Kiewa and Murray Rivers at 497544 is a typical example with moderate solum development. Only the soil profile on the Noorongong pedo-morpholith, the oldest of these four units, has a narrow (30-50 cm) zone of weakly developed pedogenetic differentiation below the solum showing a fine pattern of clayskins in fine cracks and pores.

*Sub-group I-b.* The pedo-morpholiths of this sub-group, grouped because of geomorphic affinities, are well represented in the belt of alluvial terraces bordering the floodplains and usually 2-4 m above the latter. Only the youngest of these, the Boorgunyah pedo-morpholith (AW4), occurs also extensively on the lower floodplains as observed particularly along the

Murray River west of Albury and Wodonga. A cross-section of the Murray Valley through the township of Old Barnawartha at 479545 (Fig. 6a) is used to illustrate the terrace relationships.

The Boorgunyah (AW4) is characterized by a soil profile showing a pronounced contrast between the solum and the deeper pedogenetic zone and represents a typical example of 'subsolum development' (van Dijk 1969). The sudden transition between the two zones, usually at a depth of 1.2-1.4 m may be marked by some bleaching. These deep-seated patterns are caused by variable development of sesquioxidic concretions and stains, clay cutans and pedotubules and are relatively coarse (0.5-2 cm in cross-section) but the soil mass as a whole is little changed by soil weathering.

A profile of the Boorgunyah is exposed in a high bank of a slightly domed floodplain ridge along the Murray River at 478549 (Fig. 6a).

In the soils of the three older pedo-morpholith units of subgroup I-b there is little contrast between the solum and the underlying soil horizons which gradually merge. There is however a progressive increase in depth of the profiles with age (Fig. 5).

A typical soil profile of the Barnawartha unit (AW5) is exposed along a section in a high road cutting in the first terrace level above the floodplain of the Murray River at 479547 (Fig. 6a).

The Kergunyah unit (AW6) is exposed in the banks of Splitters Creek at 483549 and along an adjacent eastern tributary, together with the Barnawartha unit at a slightly lower level on low angle alluvial-colluvial fans graded to terrace benches just above the floodplain of the Murray at 485548.

The Mullagong pedo-morpholith (AW7) seems of very restricted occurrence and only small terrace-bench remnants have been observed on the west side of the Kiewa Valley near Tawanga township, and in the Yackandandah Valley. A cross-section at the latter site about halfway between Allans Flat and Staghorn Flat (489521), shows a stepped terrace sequence of the alluvia of the Barnawartha, Kergunyah and the Mullagong pedo-morpholiths as a composite cut-and-fill in an extensive deposit of alluvium of the next older pedo-morpholith, the Mudgeegonga (AW8).

(ii) The pedo-morpholiths of Group II are the principal units of the undulating-rolling to low hilly topography of the valley plains.

*Sub-group II-a.* The Mudgeegonga (AW8) and the Baranduda (AW9) units are grouped together for three reasons.

Firstly, they both stand out as major, often locally extensive terrace formations some 5-8 m above the floodplains (Fig. 6b). Secondly, they are found

<sup>5</sup>Grid references from 1:250,000 map sheets Wangaratta SJ55-2 and Tallangatta SJ55-3 for typical exposures.





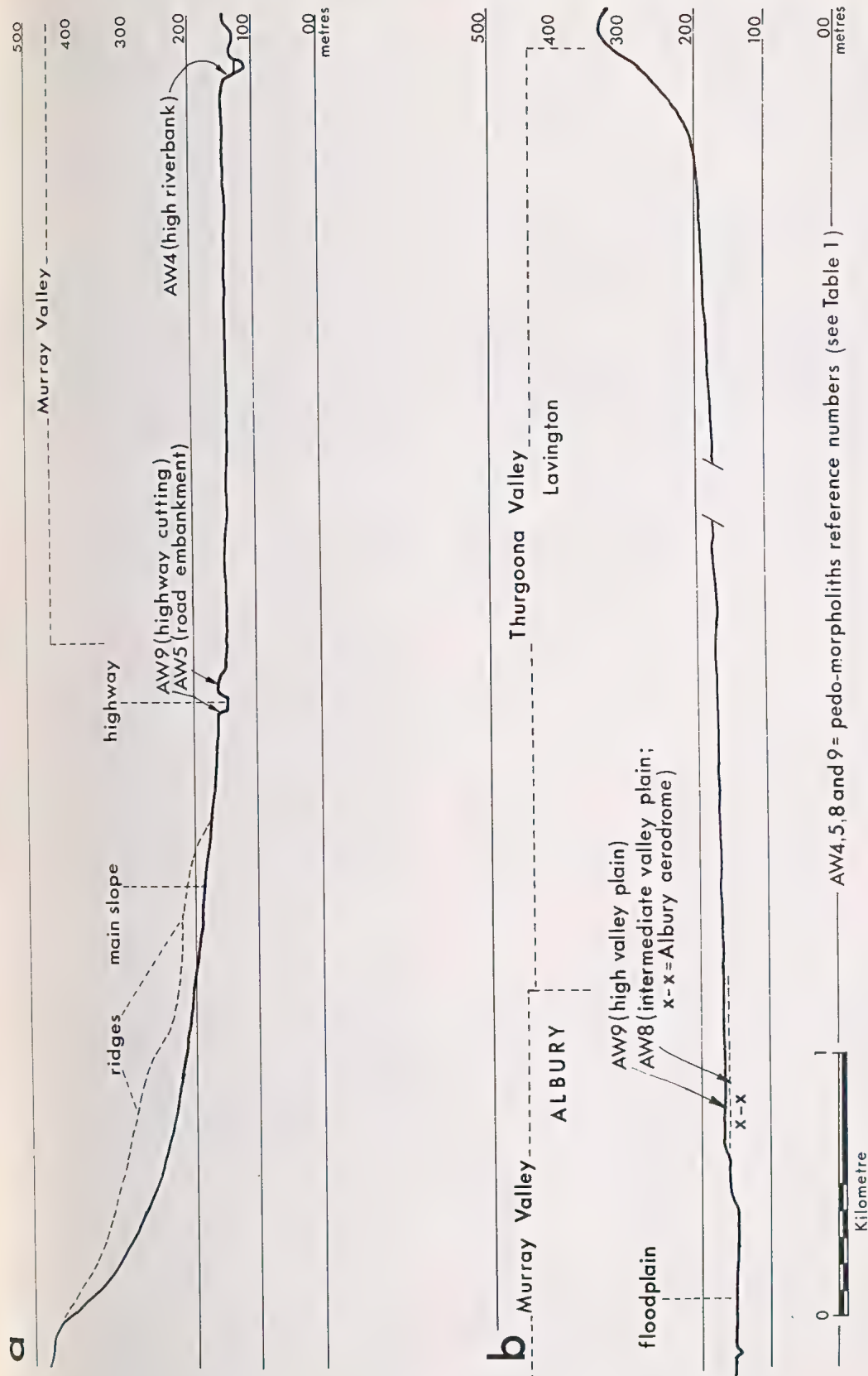


Fig. 6—Murray Valley sections. (Locations are shown in Fig. 2.)



together in the deep colluvial mantles of the lower section of long gentle slopes where they cause very conspicuous, strongly contrasting soil layering in roadside exposures. Thirdly, their erosional forms occur in a characteristic sequence in the head sections of small tributary valleys, showing a dell-in-dell arrangement.

The Mudgeegonga pedo-morpholith is widely distributed both on the higher valley floor margins and on hillslopes, whereas the Baranduda pedo-morpholith is present as thick mantles mainly on the floors of basin-shaped valleys and dells and on gentle footslopes at the base of higher relief, thinning out rapidly towards higher slopes.

The Mudgeegonga pedo-morpholith stands out, not only because of its wide distribution on both valley floors and hillslopes, but especially because of its unique soil profile development.

The soils are characterized by a deep development comprising a duplex solum, usually with only moderate contrast between A and B horizons, and a deeper-seated zone (subsolum) with strong weathering similar to that of the B horizon of the overlying solum.

The A horizon is usually an apedal greyish brown to brown loam to clay loam, about 25 cm thick, grading over 5 cm to a well-structured reddish brown clay of the B horizon. The latter clay has well-developed multi-angular peds, of 2-3 cm size, breaking down readily to smaller aggregates, and the soil material is of friable consistence.

The B horizon grades to the clay subsolum at about 90-100 cm depth. There is a colour change to more yellow- and grey-brown. The subsolum clay also has well-developed pedality, with angular peds of 3-4 cm size. The soil material is somewhat more plastic than that of the solum.

Often the deeper zone differs markedly in colour and to a lesser extent in structure from the upper B horizon so that the profile as a whole appears conspicuously layered. In fact, it often strongly resembles profiles in which two soils of different age are superimposed, particularly when a bleached horizon with sesquioxidic segregations is present between the two soil layers.

The soils of the Baranduda pedo-morpholith contrast strongly with those of the Mudgeegonga because they are commonly dark grey clays, moderately dense and of high plasticity. The upper 2-3 m usually have well-developed pedality, with coarse prismatic peds (5-10 x 10-20 cm) with widely spaced slickensides. The degree of pedality diminishes rapidly in the lower part of the profile, though slickensides may still be present; the soil texture decreases to a somewhat lighter clay, there is less biotic homogenization, and less masking of coarser grain fractions by clay weather-

ing than occurs in the upper part of the profile, so that some of the depositional fabric remains visible.

In general, the predominant clay factor in the upper part of the soil profile of the Baranduda pedo-morpholith seems to be the result of intensive clay weathering and/or internal translocation rather than of depositional origin since it occurs not only in low-lying fills of gentle gradient but also in slope colluvia and fans with relatively steep gradients.

Because the Baranduda pedo-morpholith usually extends over a wide hydromorphic reach, it frequently occurs in sharp contrast with brown and red-brown soils of other pedo-morpholiths which occur alongside or overlies it, and in a few cases with red to red-brown soils of older pedo-morpholiths under it. These latter cases illustrate significant differences in hydromorphic reach. Another conspicuous feature of the Baranduda are thick, usually 0.5-1 m, but sometimes up to 1.5-2 m, grey hardpans in very irregular bands. These occur in stony colluvia at the base of steeper, high slopes or in colluvial fans of steep gradient at the outlets of small catchments.

*Sub-group IIb* comprises the Gundowring (AW10) and the Yackandandah (AW11) pedo-morpholiths which are the major units of the 'red' soil landscapes of the higher topographic positions on the valley plains, high bench remnants, high head sections of tributary valleys, and some isolated hills and ridges. A representative example of such soil landscapes has been mapped as the Yackandandah land system by Rowe (1972).

The Gundowring unit occurs extensively as colluvial mantles on the gentle slopes of this soil landscape, and in places there are large-scale fans and trails in the downstream portions of the valleys. Well-developed fans of this unit are found north-west of Dederang at 499501.

Residual hills, ridges, and narrow bench remnants consisting of red-coloured sandy or gravelly alluvium in the main valleys, to which the surface of the remnants of the Gundowring unit in the tributary valleys appears to be graded, indicate the original existence of high alluvial valley fills related to this pedo-morpholith. Examples of these occur in the Murray Valley near the junction with the Kiewa River up to the present 170 m contour line (e.g. at Bonegilla, 498543).

The soils of the Gundowring unit show intense weathering to considerable depths of up to 10 m and more. The common colour is strong red-brown and they are clay with earthy appearance in the lower profile, often with moderate to strong pedality (0.5-2 cm irregular peds). In many places there is a more or less strongly developed, grey to pale yellow coloured, vermiform pattern resembling filled in worm or root channels 1.5-2 cm in diameter.



Exposures of the Yackandandah pedo-morpholith are characterised by the presence of hardpans which have a conspicuous network of 2-4 cm wide pallid veins, 30-50 cm apart, in a red-brown to red groundmass (500538). They occur most frequently on higher valley floor levels at the heads of the tributary valleys but can be traced down the valleys on occasional bench remnants at a somewhat higher level than those of the Gundowring unit, for instance in the Murray Valley at the junction with the Kiewa River.

The characteristic morphological relationships of the Gundowring and the Yackandandah units are best seen at the heads of the larger tributary valleys such as the Yackandandah Valley. The Gundowring unit appears to be related to small valley basins of tributary streamlets and the Yackandandah unit to a broad, undulating higher level which represents the remnant of the floor of an old, wide, major valley head basin.

(iii) The pedo-morpholiths of Group III, the Tallangatta (AW12) and the Stanley (AW13), are represented by residuals on the very high margins of the valleys defining the outline of the valley plains. A limited examination only has so far been made, but two distinct developments can be traced throughout the region using both soil and geomorphic evidence.

The Tallangatta pedo-morpholith is identified by specific types of lateritic weathering patterns in the hardpans of remnants of ancient fans and high, sloping benches (515530). It occurs at high levels on the upper flanks of the valleys close to the steep valley sides. The dominant pedogenetic pattern is characterised by a very coarse irregular network of strongly cemented red-brown to purple-red material, 5-20 cm wide, enclosing somewhat softer pallid material 15-20 cm in diameter.

The Stanley pedo-morpholith is represented by a second high level of very strongly worn bench remnants, generally occurring in the main valleys some 20 to 30 m above the level of the Tallangatta landforms.

A characteristic change in slope physiography is associated with the high level of the Stanley pedo-morpholith. Above this level the general slopes have a relatively broad, even 's'-shape but below this level the slope physiography is more complex in detail, showing conspicuous breaks of slope and a stepped sequence of ridges, spurs, and hills.

The Stanley unit is particularly extensive along wider cove-shaped valley sections. Intensive and deep rock weathering has occurred at these high levels and is clearly evident in mining excavations at the head of the Yackandandah Valley (482516).

There is approximate correspondence between the levels of the remnants of the Stanley pedo-

morpholith in the Murray Valley near Albury and those on the surfaces of the broad high-level valley corridors and associated broad valley basins in the Gerogery, Jindera, and Bowna districts north of Albury.

## DISCUSSION AND CONCLUSIONS

Correlation of pedo-morpholiths and reconstruction of a soil-stratigraphic sequence are difficult because a complete sequence is seldom available at any local valley cross-section.

However, the reconstruction of a complete valley sequence from the data of several incomplete sequences is facilitated by the fact that the sequences mostly overlap. In addition, the independent use in correlation of two separate kinds of criteria, pedogenetic patterns and geomorphic characteristics contributes to reliability.

Correlations allow the reconstruction of a general soil-stratigraphic sequence for the Albury-Wodonga region which is presented schematically in Fig. 7 for a major valley section.

In the geomorphogenetic evolution of the landscape, as related to the pedo-morpholith sequence, three main geomorphogenetic periods may be recognised:

(i) During the first period, embracing the development of the pedo-morpholiths of group III (Table 1) a landscape formed apparently characterized by lowlands of wide, trough-shaped valley plains and higher land with very smooth, rounded hills with long gentle footslopes graded to the lowlands. The valley plains had a complex branching system in which individual branches either joined tributary valleys of adjacent catchments or rejoined their own system. An example of the former is the Gerogery Valley and of the latter, the Bandiana Valley (Fig. 3).

Another characteristic of the lowlands of this early landscape development is the deep zones (up to 90-130 m) of intensive rock weathering as revealed in the borehole information of the Water Resources Commission of N.S.W. Such thick zones of decomposed rock survived the degradations of the next episodes in many locations, e.g. on the Gerogery and Jindera valley plains (Fig. 3), and they are also common at the heads of tributary valleys on high bench remnants and 'hanging' floors of small tributary branches, for example west of Yackandandah township.

(ii) During the second main period, embracing the formation of the four pedo-morpholiths of group II (Table 1) the broken topographic relief of the valley plains was sculptured and three categories are recognised.



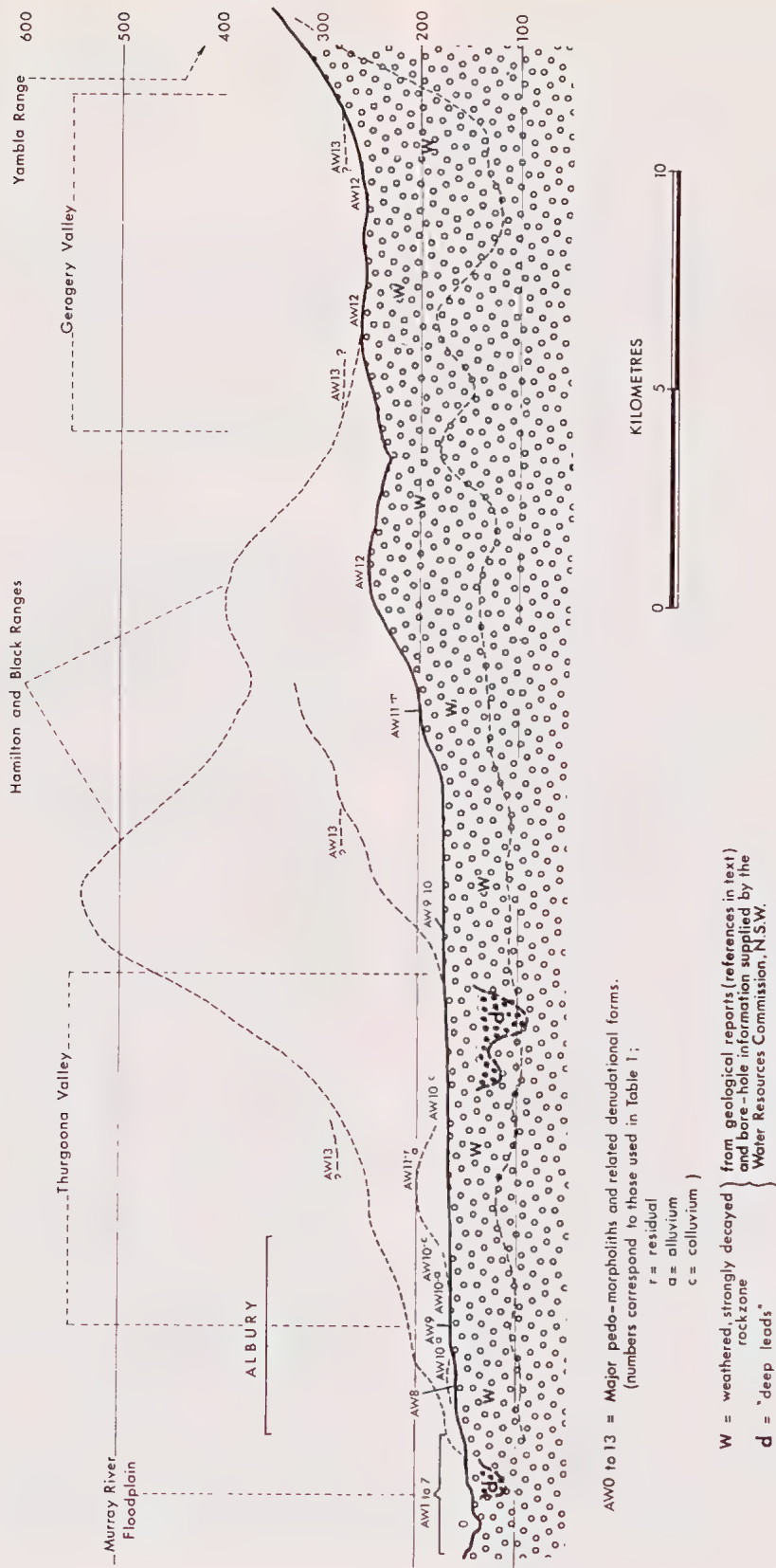


Fig. 7—Schematic soil-geomorphic section across the Murray, Thurgoona and Gerogery valley plains (see Fig. 3). Location of section is indicated in Fig. 2.

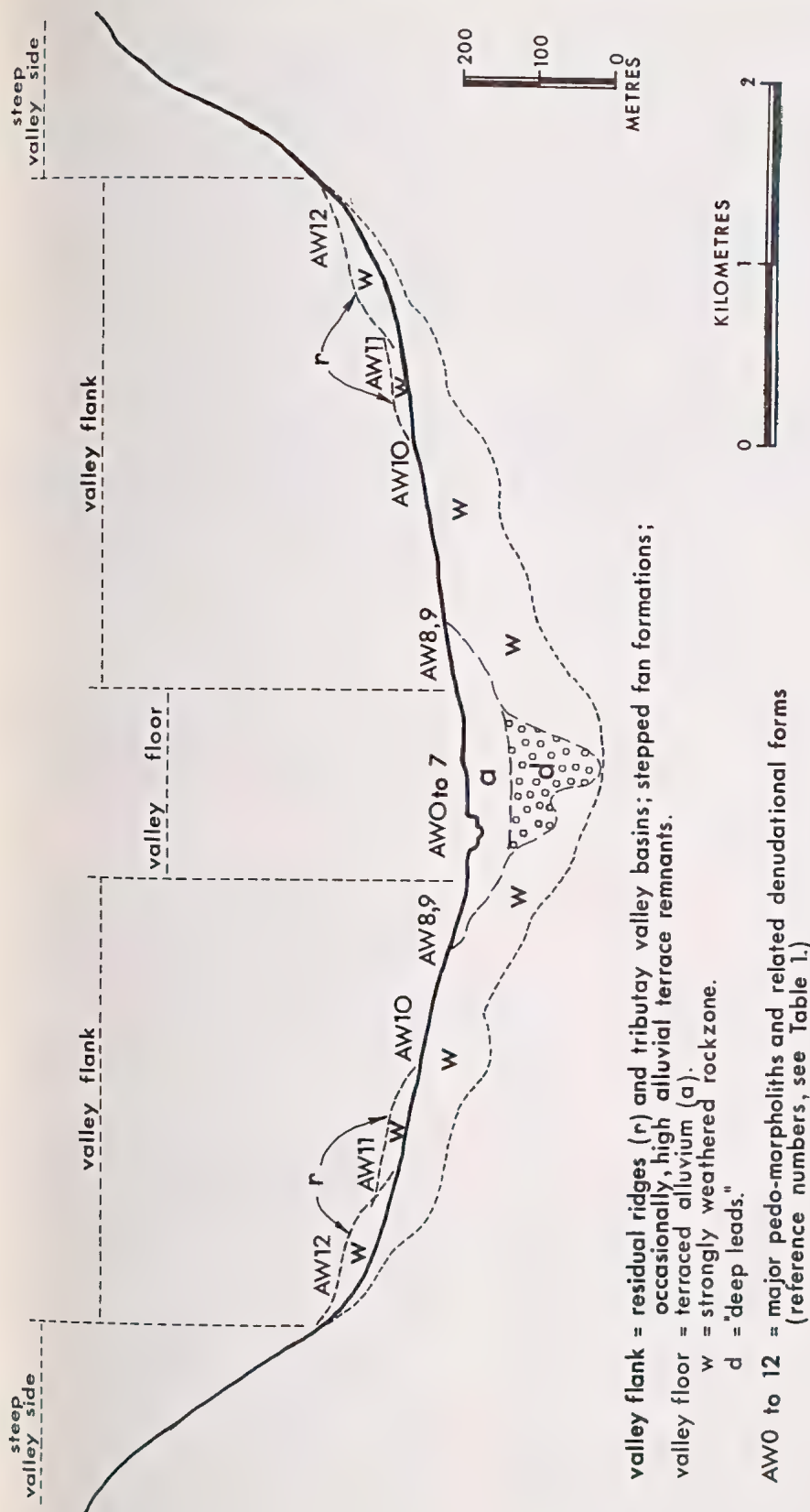


Fig. 8—Schematic cross-section of a tributary valley in the Albury-Wodonga region.



Firstly, a stepped sequence of residual ridges and hills on the higher valley sides formed, mainly by landscape degradation during the development of the Yackandandah (AW11) and Gundowring (AW10) pedo-morpholiths. Secondly, there are the breaks in slope on the gentle footslopes of the valley sides which resulted from valley-in-valley developments mainly related to the Gundowring (AW10), Baranduda (AW9), and Mudgeegonga (AW8) pedo-morpholiths. Thirdly, there are the terraced remnants of colluvial and alluvial mantles in the central valley to which all four pedo-morpholith developments of this period contributed.

(iii) During the third main geomorphogenetic period, embracing the eight pedo-morpholiths of group I (Table 1) only relatively minor landscape modifications occurred. The more significant were virtually restricted to terracing in low alluvial and colluvial belts of the valley floors, and to some stripping and ravine development on very steep slopes. Terraces of the four older pedo-morpholiths of this period (sub-group Ib, Table 1) generally dominate in the smaller tributary valleys, whereas the terraces of the younger set (sub-group Ia, Table 1) dominate on the floodplains of the main streams. The terrace of the Barnawartha (AW5) unit is often prominent in both situations.

The cross-section of Fig. 8 illustrates the results of the soil-geomorphic developments of the three main periods summarized above on the soil landscape development of the major valleys. The deep central valley fill is characteristic but deposition on the wide gently sloping margins is generally confined to relatively thin sheets of pedisements overlaying more or less decomposed rock and to local fans of the valley side tributaries. This is in contrast to the type of valley cross-section described by Lawrence *et al.* (1976, Fig. 9 2B) for major valleys in the adjacent mountainous regions where deep depositional bodies are shown across most of the valley section with a base and central core of alluvium and deep piedmont deposits on the upper sides.

The strong topographic contrasts which have developed during the development of the pedo-morpholiths indicate a considerable age span during the evolution of the present soil mantle. No actual dates for pedo-morpholith development are available but a tentative correlation with soil stratigraphic layers in the Goulburn Valley dated by Bowler 1967 can be made. These were assessed as between 250 and 30,000 years, and can be arranged in a sequence of increasing age on the basis of the pedological characteristics of sola and subsola which appear to correspond to the sequence of soils found on the five youngest pedo-morpholiths in the Albury-Wodonga region. According to this tenta-

tive correlation, the oldest dated soil sediment (about 30,000 years) in the Goulburn Valley seems to correlate with the Boorgunyah (see I-b in Table 1).

A tentative appraisal of the age of the older pedo-morpholiths of the high valley sides can be attempted through their geomorphic resemblance to the piedmont landscapes flanking the Central Highlands (Jenkin 1976, Table 10.1, p. 331). Jenkin implies that these piedmont landscapes probably originated in late Tertiary times. A considerable age for the older pedo-morpholiths is also indicated by the similarity of their pedological patterns to those of lateritic soils on land surfaces of Tertiary age.

## ACKNOWLEDGMENTS

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The continued interest in this study shown by the Soil Conservation Authority of Victoria has facilitated much of the field work on which the paper is based. The Authority has also allowed the use of unpublished data from land system surveys in the area.

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ON *Brachionus dichotomus*, SHEPHARD, 1911 (ROTATORIA: BRACHIONIDAE) FROM THE AUSTRALIAN REGION, WITH A DESCRIPTION OF A NEW SUBSPECIES, *Brachionus dichotomus reductus*.

By WALTER KOSTE\* AND RUSSELL J. SHIEL†

ABSTRACT: *Brachionus dichotomus* Shephard, 1911, hitherto regarded in the literature as a doubtful species, is recorded from waters of eastern Australia. It is a valid species related to the *Brachionus caudatus* group. An intermediate, *Brachionus dichotomus reductus*, is described and figured. Ecological and distributional information is also given.

## INTRODUCTION

*Brachionus dichotomus* was first described and figured by Shephard (1911:P1. XXII, Figs 3, 4) from waters at Templestowe and Black Rock, Victoria. Only Harring (1913: p. 21) recognized the validity of the species. In the absence of further information, Ahlstrom (1940: p. 164), in his revision of the genera *Brachionus* and *Platytias*, included the species as a probable synonym of *B. falcatus* Zacharias, 1898, noting, however, 'If . . . Shephard's description is accurate, *Brachionus dichotomus* is a distinct species'. This uncertainty led to the exclusion of *B. dichotomus* from the list compiled by Gillard (1948: p. 210-211) of the known species of *Brachionus*. Voigt (1957: p. 157) mentioned the species with the imperfectly described forms of the genus, giving a figure (Tab. 72: Fig. 24). *B. dichotomus* was absent from Ruttner-Kolisko's (1972, 1974) comprehensive and definitive work on the planktonic Rotatoria, and Koste (1978: p. 83), on the basis of a literature search, found that the species was unheard of in the 66 years following its first description.

Surprisingly, in 1977, 1978 and 1979, populations of *B. dichotomus* were found in waters of Queensland, New South Wales and the Northern Territory by B. V. Timms, Avondale College, N.S.W. and R. J. Shiel, Dept. of Zoology, University of Adelaide. Examination of samples from the latter collector revealed that *dichotomus* indeed shows significant deviations from other species of the genus *Brachionus* Pallas with respect to morphology and especially to lorica spines (Figs. 1, 3, 5). A comprehensive account of rotifer morphology is given by Koste (1979).

In the communities of two biotopes were found forms with virtually similar lorica morphology, but with shorter spines. Comparison of the distinctive and characteristic markings of both taxa established that they were modifications of the same species. However the dissimilar size and form of the subitaneous eggs (Figs. 5a and 6a) and juveniles hatched from them (Figs. 5b and 6b) show a genetic separation of both populations. Several taxonomic features of the new form are intermediate between the type *B. dichotomus* and the *Brachionus caudatus* group, suggesting the affinity of *B. dichotomus* with the *B. caudatus* group, which belongs to the Formenkreis *angularis* (Figs. 8-9), and not, as previously incorrectly assumed, with the species group *falcatus* (Fig. 7), following Koste (1978: pp. 68, 81-84).

All figures were produced for comparative purposes in the course of the study. In addition data are given on the ecology and distribution of this probably endemic species and subspecies. Tables 1 & 2 give pertinent information on the present samples. The only other record of *B. dichotomus* after Shephard's initial records from Melbourne (37°49'S/144°58'E) is by Dr. B. V. Timms from farm dams at Gloucester, N.S.W. (32°01'S/151°58'E) (Sudzuki & Timms, in prep.).

## MATERIALS AND METHODS

The available samples (#396, #572 and #589 from Shiel's collections) are subsamples, therefore an exact quantitative examination must be dispensed with. The dominance of warm, stenothermal rotifer species is, however, recognizable. Among these are

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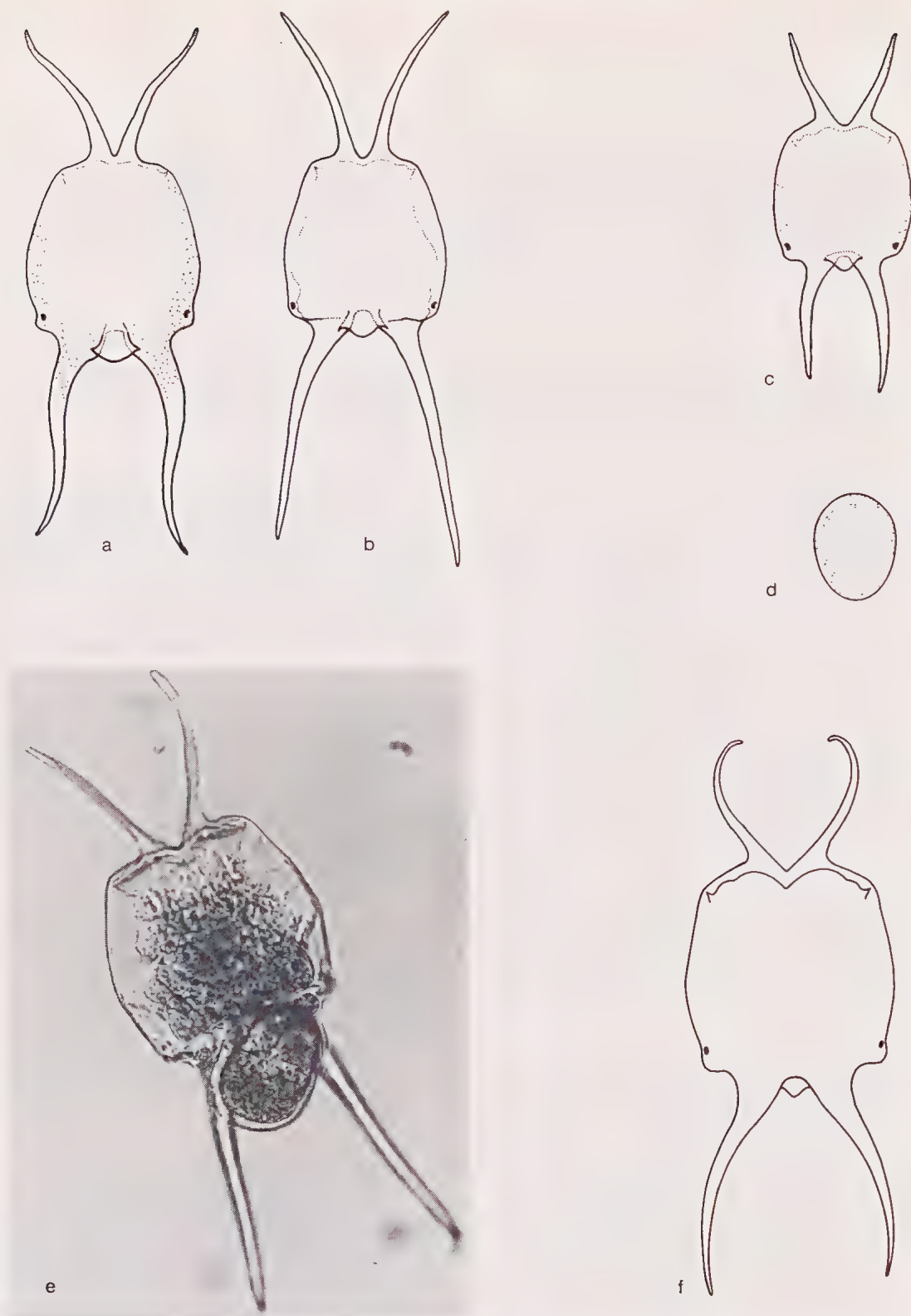


Fig. 1—*B. dichotomus dichotomus* a. Lorica ventral, 448  $\mu\text{m}$ ; b. Lorica dorsal; c. Lorica, juvenile, 304  $\mu\text{m}$ ; d. Subitaneous egg, 88/64  $\mu\text{m}$ ; e. amictic female with subitaneous egg; f. lorica ventral, 245  $\mu\text{m}$ . a-e from Sawpit Lagoon, f. from Lake Mulwala.

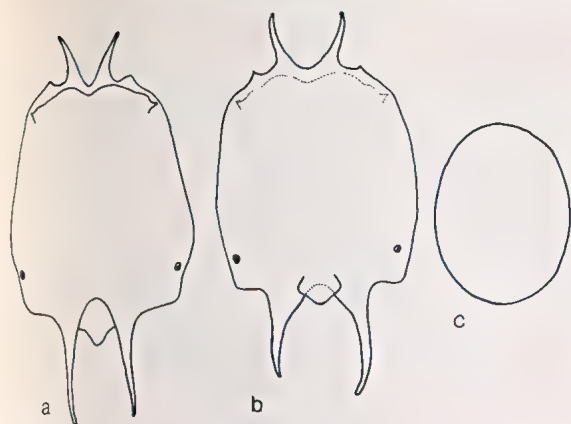


Fig. 2—*B. dichotomus reductus* Koste & Shiel, ssp. nov. a. loricula ventral, 148  $\mu\text{m}$ ; b. loricula dorsal; c. Subitaneous egg, 68/48  $\mu\text{m}$ . a, b from sample 589.

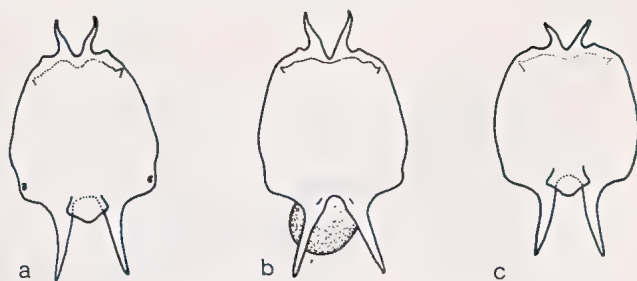


Fig. 4—*B. dichotomus reductus* a. loricula dorsal, 180  $\mu\text{m}$ ; b. loricula, ventral, with subitaneous egg (See Fig. 7a), 168  $\mu\text{m}$ ; c. loricula, dorsal.

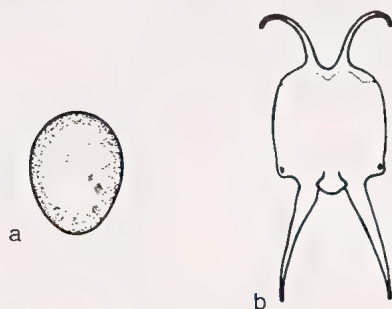


Fig. 5—a. *B. dichotomus* type, subitaneous egg, 80/60  $\mu\text{m}$ ; b. *B. dichotomus* juvenile 208  $\mu\text{m}$ .

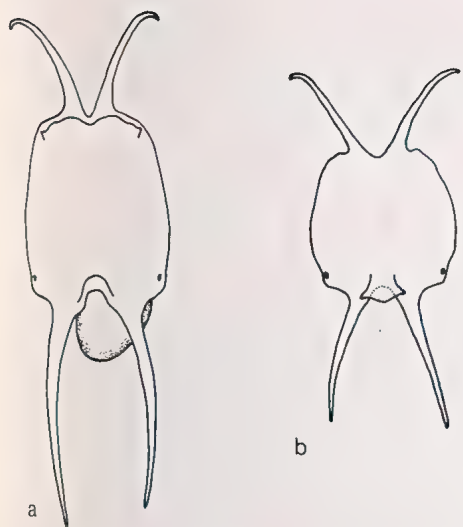


Fig. 3—a. *B. dichotomus* female with subitaneous egg, ventral, 372  $\mu\text{m}$ ; b. juvenile animal, dorsal. From sample 572.

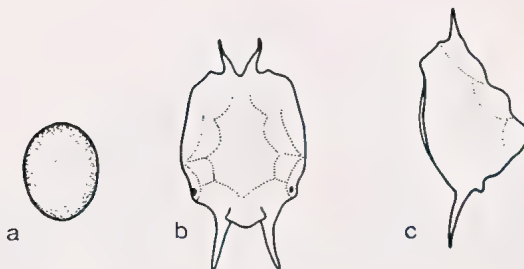


Fig. 6—a. *B. dichotomus reductus*, subitaneous egg, 64/44  $\mu\text{m}$ ; b. *B. dichotomus reductus*, dorsal loricula facetation; c. loricula, lateral.



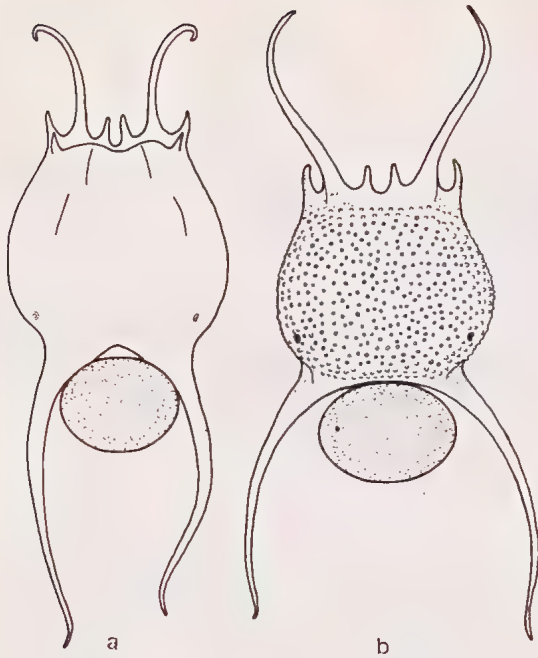


Fig. 7—*Brachionus falcatus*. a. ventral; b. dorsal; c. ventral; d. subitaneous egg. Samples from the Murray-Darling River system.

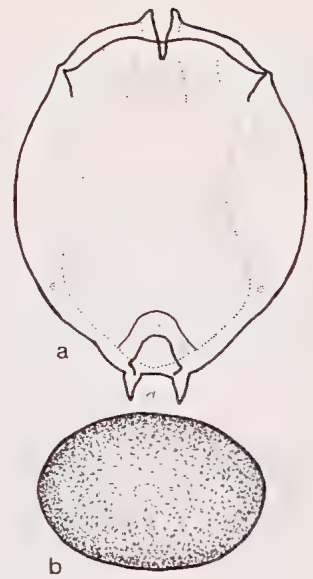


Fig. 8—*Brachionus angularis* f. *bidens* (Plate, 1886) from the River Murray. a. lorica ventral, total 135  $\mu\text{m}$ ; b. Subitaneous egg, 77/53  $\mu\text{m}$ .

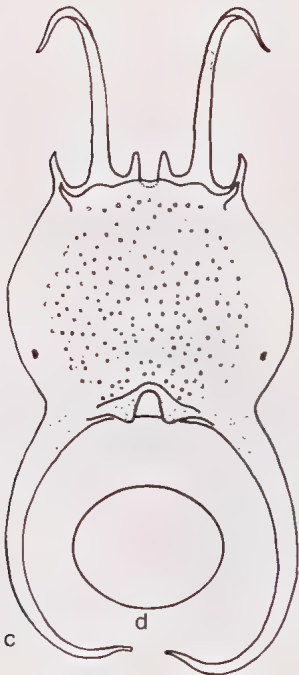


Fig. 9—An aberrant form of *Brachionus angularis* Gosse, 1851, from the River Murray system. Lorica dorsal, total 100  $\mu\text{m}$ .

TABLE 1  
PHYSICO-CHEMICAL PARAMETERS FOR THE HABITATS WHERE  
*B. dichotomus* IS RECORDED.

Locality	1 'Sawpit Lagoon', near St. George, Qld. Shallow open water.	2 Billabong of Mitta Mitta R. near Eskdale, Vic. <u>Juncus</u> .	3 Lake Mulawala, near Yarrowonga, Vic. Open water <1m.
Grid ref.	28°35'S/148°50'E	36°28'S/147°15'E	36°01'S/146°00'E
Collection date & number	23.05.78, #396	02.02.79, #572	04.02.79, #589
Water temp. °C	22.5	29.2	24.2
Dissolved oxygen ppm	8.4	8.0	8.2
pH	7.7	7.5	7.7
Conductivity μS	122	85	60
Turbidity NTU's	95	6	22

both cosmopolitan species, e.g. *Hexarthra mira*, and also pansubtropical and tropical species (*Brachionus falcatus*, *B. quadridentatus melheni*, *Filinia opolien-sis*, *F. pejeri*, *Keratella lenzi*, *K. tropica*, *K. pro-curva*, *Sinantherina semibullata*, *Testudinella triden-tata*). *Brachionus dichotomus* f. typ. and the new form are apparently endemic. The taxa of this species group occur sympatrically in two biotopes (samples 572 and 589) but only the f. typ. occurs in sample 396.

*Species populations of the Group B. dichotomus in three samples:*

*Sample 396.* From Table 2 it can be seen that *B. dichotomus* is the dominant form in this 'lagoon' (in fact a billabong of the Moonie River, Qld). Individuals are present with the long-spined lorica (Figs. 1, 3) distinctive of Shephard's described type (1911 Figs. 3, 4). In Fig. 1c is shown a lorica of 303 μm total length, including spines. Apparently this is from a juvenile (cf. Fig. 5b). The other adult loricate females have lorica lengths of 400-488 μm (Fig. 1a-b). The greatest lorica width in this population measures 148 μm. Shephard's measurements of 'length overall 0.3 mm, breadth 0.1 mm' are exceeded, indicating that this population has a larger lorica measurement (see Table 3). The dorsally curved anterior spines reach a length of 140 μm, the caudal spines 200 μm. Five females carried subitaneous eggs (88 μm long × 66 μm wide) on the dorsal lorica (Fig. 1e).

*Sample 572:* Two forms of *B. dichotomus* occur in this biotope, belonging to sympatric populations rather than to a polymorphic single population. The first form corresponds fully to the type. Juvenile individuals have lorica lengths of 200-288 μm (Fig. 1f). The adult lorica measures 380 μm (Fig. 3a). The subitaneous egg measurements (Fig. 5a) vary between 80-88/62-64 μm. The second form (Fig. 5) resembles *Brachionus caudatus* f. *vulgatus* Ahlstrom, 1940, so that initially it was not thoroughly examined (see Ahlstrom Plate VI, Figs. 6, 9, 10). On later detailed examination the affinity with *dichotomus* was established. See description of the new subspecies.

*Sample 589.* This sample, from Lake Mulwala, an impoundment of the Murray River below Lake Hume, contains a species-rich rotifer fauna in which pelagic and semi-pelagic forms are dominant, and *B. dichotomus* plays an insignificant role. The individual figured in Fig. 1f does not differ morphologically from the type, although the lorica length is small at 245 μm (cf. Figs. 1a & 1b). Figs. 2a-c show the external lorica appearance of a contracted fertile female *B. dichotomus* (second form) with subitaneous egg.

*Brachionus dichotomus* (second form):

The form of the lorica of this rotifer agrees fully with the type, shown by the deep insertion of the lateral antennae almost at the level of the top of the boundary of the ventral foot-opening, underlying which is the



TABLE 2  
ROTIFERS FOUND IN THE THREE HABITATS OF TABLE 1

Habitats (Table 1)	1	2	3
<i>Anuraeopsis navicula</i> <i>navicula</i> Rousselet, 1910	—	22	8
<i>Asplanchna priodonta</i> <i>priodonta</i> Gosse, 1850	—	19	16
<i>Asplanchna sieboldi</i> i (Leydweg, 1854)	4	18	—
<i>Brachionus budapest-</i> <i>iensis</i> (Daday, 1851)	—	1	—
<i>B. calyciflorus</i> f. <i>anuraeformis</i> (Brehm, 1909)	7	8	1
<i>B. calyciflorus</i> <i>calyciflorus</i> Pallas, 1766	—	10	—
<i>B. dichotomus dichotomus</i> Shephard, 1911	14	16	2
<i>B. dichotomus</i> var <i>reductus</i> n. spp.	—	27	4
<i>B. falcatus</i> Zacharias, 1898	1	52	—
<i>B. lyratus</i> Shephard, 1911	—	26	—
<i>B. quadridentatus</i> <i>melheni</i> (Barrois & Daday, 1894)	—	6	—
<i>Collotheca</i> c.f. <i>mutabilis</i> (Hudson, 1885)	—	10	—
<i>Collotheca</i> c.f. <i>ornata</i> <i>ornata</i> (Ehrenberg, 1832)	—	1	—
<i>Conochilus dossuarius</i> <i>dossuarius</i> (Hudson, 1875)	5	—	12
<i>Conochilus natans</i> (Seligo, 1900)	—	—	2
<i>Euchlanis meneta</i> Myers, 1930	—	—	3
<i>Filinia longiseta</i> <i>longiseta</i> (Ehrenberg, 1834)	—	5	—
<i>F. longiseta</i> var. <i>limnetica</i> (Zacharias, 1893)	—	9	—
<i>F. longiseta</i> var. <i>passa</i> (O.F.M., 1786)	2	—	—
<i>F. opoliensis opoliensis</i> (Zacharias, 1898)	2	—	—
<i>F. pejleri pejleri</i> Hutchinson, 1964	—	—	8
<i>Floscularia ringens</i> <i>ringens</i> (Lamarck, 1758)	—	—	3

	1	2	3
<i>F. janus</i> (Hudson, 1881)	—	—	2
<i>Hexarthra mira mira</i> (Hudson, 1871)	—	84	23
<i>Keratella cochlearis</i> (Gosse, 1851)	—	247	4
<i>K. lenzi lenzi</i> (Hauer, 1953)	—	—	1
<i>K. procurva</i> (Thorpe, 1891)	2	—	7
<i>K. tropica</i> (Apstein, 1907)	12	122	12
<i>K. valga</i> (Ehrenberg, 1834)	—	—	3
<i>Lacinularia</i> sp.	—	—	4
<i>Lecane bulla</i> (Gosse, 1886)	—	2	11
<i>L. crepida</i> Harring, 1914	—	—	1
<i>L. (s.str) hornemanni</i> (Ehrenberg, 1834)	—	1	—
<i>L. luna luna</i> (O.F.M., 1776)	—	—	4
<i>L. lunaris crenata</i> (Harring, 1913)	—	—	1
<i>L. signifera signifera</i> (Jennings, 1896)	1	—	—
<i>L. signifera</i> var. <i>ploenensis</i> (Voigt, 1902)	—	—	1
<i>Macrochaetus subquadratus</i> Perty, 1850	—	3	—
<i>Polyarthra vulgaris</i> Carlin, 1943	—	135	42
<i>Sinantherina</i> c.f. <i>semibullata</i>	—	—	2
<i>Synchaeta stylata</i> Wierzejski, 1893	—	—	64
<i>Testudinella tridentata</i> Smirmov, 1931	—	—	1
<i>Trichocerca pusilla</i> (Lauterborn, 1898)	—	—	6
<i>T. similis similis</i> (Wierzejski, 1893)	11	—	—

TABLE 3

COMPARATIVE MEASUREMENTS OF THE TWO FORMS OF

*B. dichotomus*.

	<i>B. dichotomus</i> <i>dichotomus</i>	<i>B. dichotomus</i> <i>reductus</i>
Total lorica length (including spines)	200-488 $\mu\text{m}$	145-180 $\mu\text{m}$
Lorica length	84-140 $\mu\text{m}$	85-100 $\mu\text{m}$
Lorica width	80-148 $\mu\text{m}$	78- 90 $\mu\text{m}$
Length of anteromedian spines	55-140 $\mu\text{m}$	18- 28 $\mu\text{m}$
Length of caudal spines	80-200 $\mu\text{m}$	30- 45 $\mu\text{m}$
Subitaneous egg	80-88/60-64 $\mu\text{m}$	68/48 $\mu\text{m}$

swollen lateral formation of the lorica, and the dorsal, somewhat domed plate over the foot-opening (cf. Figs. 1a & 2b). This plate is described in Shephard's type description as follows: 'There is also at the posterior end, overhanging the bases of the spines, a projecting plate having a gentle outward curve in the centre, and a sweeping outwards at each side to form two short, acute points' (c.f. Figs. 2b & 6b, c). Such a configuration of the dorsal boundary of the foot-opening is not known in *B. caudatus* forms (Ahlstrom 1940, Tables VI-VII). The lorica of the new form reaches a total length (including spines) of only 145-180  $\mu\text{m}$ . The anteromedian spines are short (18-28  $\mu\text{m}$ ). Whereas anterolateral spines as found in the f.typ. are absent, rudimentary anterosubmedian spines are present. Fig. 3b indicates that such rudiments occasionally appear also in juveniles of *B. dichotomus* f.typ. The lorica of the new form is 60-64  $\mu\text{m}$  high (Fig. 6c). The dorsal plate is occasionally faceted (Fig. 6b). The asymmetric posteromedian spines are conspicuously short (30-36/40-45  $\mu\text{m}$ ). The subitaneous egg measures 68/48  $\mu\text{m}$ . Juvenile individuals (Fig. 6b) hatched from these reproductive bodies are distinctive in their appearance compared to f.typ. individuals of an essentially corresponding age group (cf. Figs. 5b & 6b).

The above-described morphological taxonomic characteristics of the lorica show a close affinity with *B. dichotomus dichotomus* Shephard 1911. However the dissimilar size of the subitaneous eggs and the form of the juvenile stage are indications of two genetically distinct populations. Also, the lack of modification of the type species raises the question of the taxonomic rank of this new *Brachionus* form. It is proposed, in the absence of geographic isolation, in a syntope (see Koste 1978: 51), to conclude that sub-specific rank is appropriate. This rotifer is therefore named

***Brachionus dichotomus reductus*, ssp. nov.**

**HOLOTYPE:** A permanent mount is lodged with the type collection of the Zoological Museum, University of Kiel, registration number Rot. 010.

**DISCUSSION**

Considerable variability (modifications) within the same population, with apparently undirected variations in the lorica spine shape and length, are not uncommon in the Family Brachionidae of the monogonontan Rotatoria (Genera: *Brachionus*, *Keratella*, *Platylas*, *Notholca*, *Anuraeopsis* and *Kellicottia*). They are observed synchronously and also at different times (seasonal polymorphism).

If populations of the same species from different ecologically distinct biotopes are examined, it is likely that they are seen as physiological races (var.) and are genetically fixed. This is illustrated by the variations in the *Brachionus falcatus* type, which the authors found in samples from different biotopes of the Murray-Darling River System (Figs. 7a-d). A comparison of this lorica form with that of the *B. dichotomus* species-group shows that any discussion on a closer relationship (Ahlstrom, 1940:164) of both species groups is unnecessary. The morphology of the *falcatus* group is comparatively constant. Only the structure of the lorica surface and the length and curvature of the anterior and posterior spines are variable.

The species-group *B. caudatus*, with its form series and taxonomic difficulties, is retained. *B. dichotomus reductus* tends towards an intermediate of this group. It has morphological conformity with *B. caudatus* f. *vulgatus* Ahlstrom, 1940 and also *B. caudatus caudatus* Barrois & Daday, 1894 (see Ahlstrom, 1940: T. VI, also Koste, 1978: T. 13, Fig. 8, 19-22). We note also that a *Brachionus* (Fig. 8) from Australian waters, with elongated foot-opening spines, can be seen to be an intermediate between the *angularis* and *caudatus* group. The taxa *B. angularis* (Figs. 8-9), *B. caudatus caudatus*, including f. *vulgatus*, as well as *B. dichotomus* (Fig. 1-6) are characterized by the absence, or only occasional occurrence or rudimentary structures (Figs. 2a-b, 4a-c) of the anterosubmedian spines. Anteromedian spines are always present. They are shortest in *B. angularis* (Figs. 8-9), longest in *B. dichotomus* (Figs. 1-6).

In the *caudatus* and *dichotomus* groups there is seen a caudally-inflexed elongation of the dorsal lorica. In *dichotomus*, however, this is terminated by a species-specific, bordered and domed tongue-shaped plate. Foot-opening spines (Fig. 8a) of variable length and form occur only in the *angularis* group. They are absent in the taxa *B. caudatus* and *B. dichotomus*.



Instead these possess narrowly-framed asymmetrical posterolateral spines of variable length.

Lorica and other measurements of the taxa are given in Table 3.

## CONCLUSION

Particularly by reason of its anteromedian spines, the species group *dichotomus* is considered a unique member of the Formenkreis *angularis* ('*angularis*-group' after Ruttner-Kolisko, 1972:166; 1974:68; 'Formenkreis *angularis*' after Koste, 1978). Taxonomically it is assigned to affinity with the *caudatus* species-group. The greatest conformity with the type *B. caudatus caudatus* Barrois & Daday, 1894 is shown with respect to lorica shape and the number of anterior and posterior lorica spines. This semi-pelagic rotifer species, hitherto found only in E. Australia, is highly likely to be endemic to this zoogeographical region. After the new finds of Berzins (1963: *Keratella (quadrata) australis*, K. (*valga*) *slacki*), Sudzuki (1975: *Brachionus baylyi*) and Koste (1979: *Brachionus keikoa*, *Keratella shieli*), it is presumable that further investigation of the rotifer fauna of Notogaea (Australia and Tasmania) will produce additional endemic species.

## ACKNOWLEDGMENTS

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## THE FLORA AND AVIFAUNA OF LADY JULIA PERCY ISLAND, VICTORIA, AUSTRALIA

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**ABSTRACT:** Unlike most Victorian islands, Lady Julia Percy Island (22 km WSW of Port Fairy) is of volcanic origin. Seals and guano were once harvested on the island which was also stocked briefly; more importantly, rabbits were liberated there. Although the island was originally described as heath or scrub-covered and treeless (as it is today), some later reports are dubious: e.g. a patch of tea-tree reported in 1886. This paper reports on surveys of vegetation and breeding colonies of seabirds made in November 1978 and January 1979 and incorporates unpublished material from other sources.

Four vegetation communities are recognised (grassland, closed-fernland, *Senecio* herbfield, and succulent herbfield) and 100 flowering plants have been recorded. The absence of a shrub-dominated community is striking and may be the consequence of edaphic and biotic factors operating in a harsh environment. The relatively high proportion (35%) of alien species (including many grasses and composites) may be due to human activity and to the unstable conditions present within the areas burrowed by seabirds. The structurally and floristically simple plant communities present little opportunity for colonisation by many passerine bird species and, although the island's list of species is extensive, most records are of isolated migrants or vagrants.

The island provides ample area for breeding seabirds. Of these, the most numerous are the Short-tailed Shearwater *Puffinus tenuirostris*, with a total number of burrows estimated at about 15,300, and the Little Penguin *Eudyptula minor*, with approximately 2,000 burrows. Such estimates are considerably lower than those previously reported by other authors and we consider that other colonies are of more importance for these species. The numbers of Fairy Prion *Pachyptula turtur* and Common Diving-Petrel *Pelecanoides urinatrix* were not estimated and attention should be paid to these two species since their Australian breeding range is centred on Bass Strait, an area for which no reliable population estimates exist.

### INTRODUCTION

Most Victorian islands are granitic, isolated from the mainland by sea level changes (see Jennings 1959), but the western Victorian islands, Lady Julia Percy and Lawrence Rocks, are volcanic in origin and may never have been connected with the mainland. Discovered in 1800 (Grant 1803), Lady Julia Percy Island was visited frequently by sealers in the early 19th century. Trigonometric stations were established there in 1840 and 1863, guano was extracted for a time, the island was stocked with pigs and horses between 1879 and 1908 and a hut was erected in 1886 (Mahony 1937). A pair of rabbits was introduced in 1868 (Mahony 1937), and numbers have increased so that they are now a dominant feature of the fauna (Tarr 1954a, b, Prescott 1968).

As part of a study of seabird colonies around the Victorian coast we visited the island in November 1978 and again in January 1979. On both occasions we collected plant specimens and mapped vegetation communities and major sea-bird breeding colonies. Previous literature and unpublished material are reviewed to provide comparative details of the past status of plants, rabbits and bird species on the island.

### PHYSICAL FEATURES

Lady Julia Percy Island, with a plateau area of about 129 ha and a total area of 140 ha, lies 5 km off the coast and is some 22 km to the WSW of Port Fairy. The island is relatively low, maximum height about 46 m, and slopes gently upwards from north to south; much of the coastline is of sheer cliffs which are, in

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PLATE 15

Talus slope, Dinghy Cove, Lady Julia Percy Island, January 1979.

places, undermined by wave action. Talus slopes are present, particularly in Dinghy Cove (Pl. 15) and Seal Bay, and basalt platforms are found around the coast.

The island, which was formed during two periods of volcanic activity, is composed of boulder tuff overlain by six lava flows (Stach 1937). Since it is surrounded by deep water (35-45 m), and a vent is present, local volcanic action was apparently responsible for the island's development (Stach 1937). The fine loam soil is generally shallow and includes gravels and ironstone concretions. It is acid (pH 4.8-6.7), with a high organic content, and the poorly developed profiles indicate a very immature soil similar to that of the Stony Rises (Edmonds 1937). Dewhurst (1937), Stach (1937) and Edmonds (1937) provide further details on the island's physiography, geology and soil.

Rainfall at Portland, the nearest mainland weather station, is 782 mm per year, mostly falling between April and November; winds are predominantly from the W in winter, and SW-SE in summer and temperatures are highest in February and lowest in July

(Bureau of Meteorology 1975, Land Conservation Council 1976). The deep waters surrounding it, and its exposure to winds from W round to SE leads to a spray being deposited on the island by most gales (Edmonds 1937).

## VEGETATION

In December 1800 Grant (1803) noted that the Island 'was covered with grass but no trees', and Baudin also commented on 1 April 1802 that the Island 'is completely treeless, appears to be covered only with a type of very low-growing heath . . .' (Baudin, 1801-7). According to Mahony (1937) the surveyor Allan reported (in 1862?) that 'the whole island is covered with low, thick scrub, rushes and creepers . . .'. In 1886 there was a patch of dense tea-tree near the southern end, with the rest of the island covered by bracken, grass and rushes (Mahony 1937). By the time of the McCoy Society's visit in 1936 no shrubs were present, nor were they expected since 'the



constant high winds, together with the shallowness of the soil on this high and most exposed place, would surely inhibit all such growth' (Edmonds 1937).

In 1936 Edmonds (1937) recognised six communities which are listed below, together with comments summarised from Edmonds. (Specific nomenclature generally follows Willis 1970, 1972, except where modified by Beaglehole 1978a, b. Names used by Edmonds or Patton, 1937 and subsequent collectors have been altered accordingly.)

1. Grassland, which took up about one third of the area; *Agrostis avenacea* predominating, with *Aira caryophyllea* being fairly common, *Briza minor* sparse, and including *Anagallis arvensis* and *Centaureum spicatum*.

2. Fernland, about a third of the island; practically pure, dense, dwarfed *Pteridium esculentum*, with *Agrostis avenacea* in places, and few *Juncus pallidus* and *J. bufonius*.

3. *Senecio lautus*, extensive, mainly on the west; *Agrostis avenacea* and *Carduus tenuiflorus* were also present.

4. Swampland, small area, almost exclusively *Chenopodium glaucum* with *Anagallis arvensis* on edges.

5. *Carpobrotus*, restricted to south, included *Dichondra repens*.

6. Celery, small patch of *Apium prostratum* at southern end.

The distribution of these communities in 1936 is shown in Fig. 1, and the species recorded by Edmonds (1937) and Patton (1937) are given in Appendix 1. Tarr (1954a), who visited the island in late 1949, noted that 'with the exception of a few clumps of rushes and a small section of *Mesembryanthemum* [*Carpobrotus*] (pigface) in the south, most of the island was covered with bracken fern, variable groundsel (*Senecio lautus*), a native plant, and a very large extent of the introduced slender shore thistle (*Carduus tenuiflorus*)'. In November 1960, 3 ferns and 85 species of flowering plants, including 29 alien species, were recorded by Beaglehole (1962), who remarked on carpets of stonecrop *Crassula* and trigger-plants *Stylidium*, and the considerable increase in numbers of alien species. Pescott (1965), who visited the island in December 1963, considered that much of the vegetation had been damaged by rabbits. During the same visit G.W.C. collected 66 species, of which 24 (36.4%) were alien. In December 1967 the vegetation was 'classified under four headings — bracken, grass, pigface and *Senecio*' by Pescott (1968), but his accompanying map also showed a small area of rushes. The area covered by bracken had apparently increased since the 1936 survey and *Senecio* had

declined. Pescott concluded that the dry conditions which had prevailed in Victoria during 1967 had not affected the bracken and pigface seriously, though the grass, thistles and most of the *Senecio* had died off leaving many acres of bare earth; rabbits were apparently eating pigface roots. In September 1972, vegetation was absent around most of the cliff tops, and severe erosion was occurring (Venn 1972). G.W.C. and A. C. Beaglehole were on the island in December 1974, and collected 82 species of flowering plants of which 29 (35.4%) were aliens.

The vegetation was mapped on 27-30 November 1978 and 23-25 January 1979, using aerial photographs (colour, taken in late December 1978) and ground surveys. Transects were established (Fig. 2) and the percentage cover provided by each species was estimated for each 10 m unit. Four vegetation communities were recognised and their distribution, together with areas of bare ground, are shown in Fig. 1. These communities, similar to those described by Edmonds (1937), were as follows (using Specht's (1970) structural forms):

#### 1. GRASSLAND

Various species of grass (predominantly *Briza minor*, *Vulpia bromoides*, *Aira caryophyllea*, *Agrostis avenacea*, *Polypogon maritimus* and *Lagurus ovatus*) formed a complex mixed community of varying height. Within the community associated herbs (e.g. *Urtica urens*, *Polycarpon tetraphyllum*, *Sagina apetala*, *Epilobium billardierianum*, *Anagallis arvensis*, *Senecio lautus*) were frequently locally dominant. Thistles, mainly *Carduus tenuiflorus* and occasionally *Sonchus asper*, occurred throughout the community and frequently formed dense stands (Pl. 16), particularly in the southern and southwestern section of the community. Such stands reduced the distinction of boundaries with neighbouring communities, especially the fernland. The thistles (*Carduus*), which reached some 0.8 m in height in November 1978, had died back and were broken down by January 1979 and bare earth was increasingly exposed.

Rocks were exposed in some places within the community, but the soil had a maximum depth of some 0.5 m in a few shearwater colonies around the periphery of the grassland. In general plant cover was almost complete, but towards the cliffs both cover and plant height were reduced. Plant heights were also reduced by grazing rabbits, exposure to wind and spray, and trampling by shearwaters.

The grassland community, which now extends along the eastern coast and across the central and southern interior part of the island, has expanded since 1936 (cf. Edmonds 1937 with Fig. 1). It has replaced *Senecio lautus* and *Carpobrotus rossii*, and to a lesser



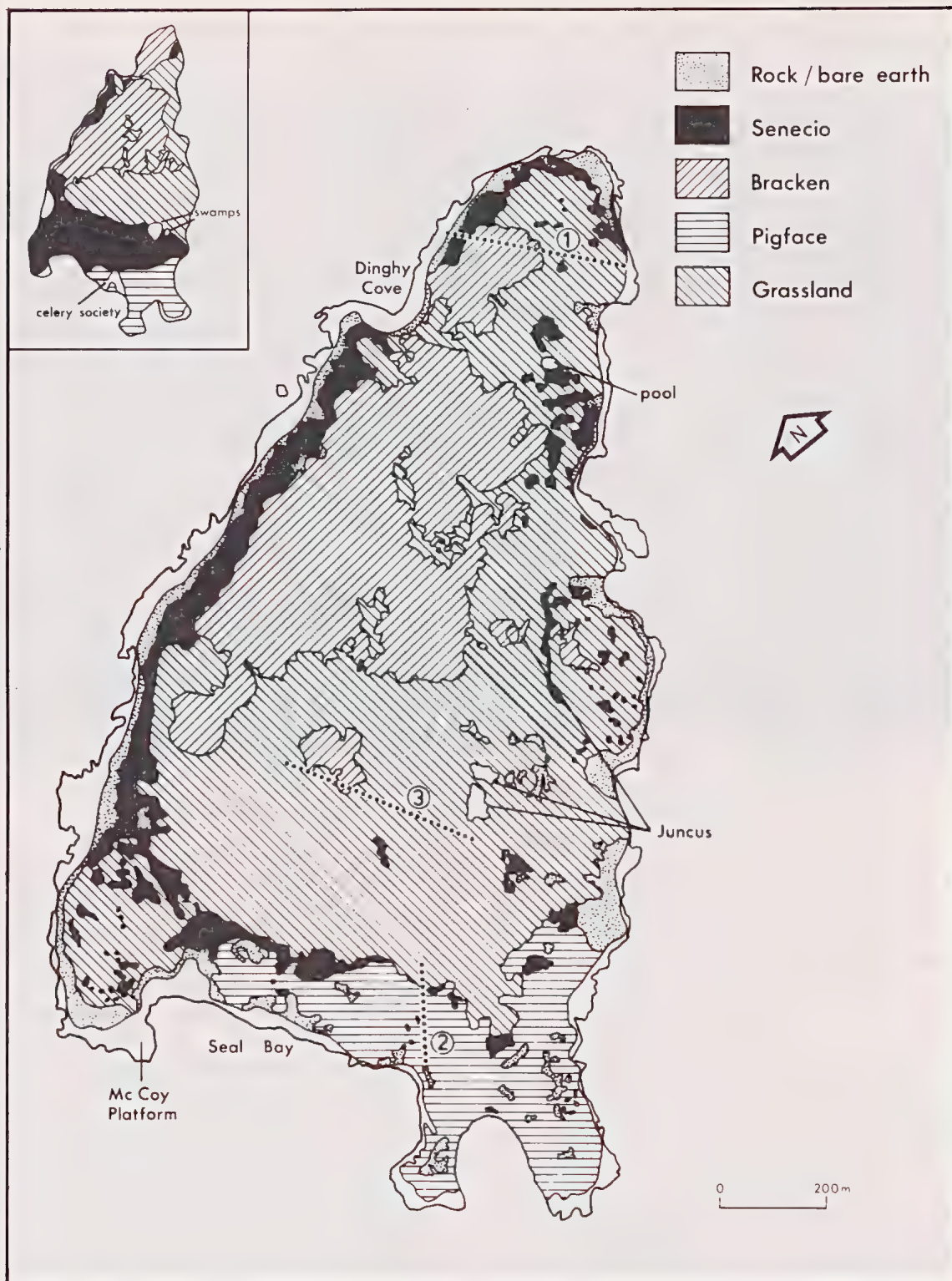


Fig. 1—Major plant communities on Lady Julia Percy Island, November 1978. Inset is a map redrawn from Edmonds (1937) showing community distribution in 1936. (Transect routes used in Fig. 2 are also shown).



PLATE 16

Area of *Carduus tenuiflorus*, southern end of Lady Julia Percy Island, along transect route 2 (on right), November 1978.

extent *Apium prostratum*, on the south and southwest, and fernland on the northeastern edge. During this survey the grassland occupied about 63 ha compared with about 22 ha in 1936 (as determined from Edmonds' map).

## 2. CLOSED FERNLAND

The shade provided by the dense overlapping fronds of *Pteridium esculentum* (Pl. 17), and the layering of tangled dead plants, has allowed few other species to become established. Although frond height sometimes exceeded 0.8 m, most plants were about 0.5 m and the average height was obviously lower near the coast. In more open areas low ground cover was provided by *Dichelachne crinata*, *Cyperus tenellus*, *Centrolepis strigosa*, *Oxalis corniculata*, *Hydrocotyle hirta*, *Anagallis arvensis*, *Dichondra repens*, and *Cotula australis*. Towards the edges of the community the bracken merged with other species.

There has been some change in the area of fernland since Edmonds' (1937) report (c.20 ha in

1936 compared with about 29.2 ha in November 1978) and the distribution has altered (see Fig. 1). Much of the northern community has been replaced by grassland, and the central portion has advanced slightly though it is not now as extensive as that shown by Pescott (1968). The community has generally retracted from the northern and northeastern cliff edge and advanced along the southwestern edge.

## 3. *Senecio* HERBFIELD

*Senecio lautus* (Pl. 18) formed a generally well-defined and robust community occupying relatively shallow soil, on which plants averaged about 0.24 m in January 1979. Often it was the only species present but the cover provided by *Senecio* rarely exceeded 50%; the remainder was bare soil. In a few areas *Vulpia bromoides*, *Agrostis avenacea*, *Polypogon maritimus*, *Anagallis arvensis* and *Carduus tenuiflorus* were associated, being locally dominant or subdominant.

The community covered some 13.4 ha com-





PLATE 17

*Pteridium* community, northern end of Lady Julia Percy Island looking southeast, November 1978.

pared with approximately 20 ha in 1936 (Edmonds 1937). The southern belt shown by Edmonds has declined whilst a narrow belt of *Senecio* now extends along the west coast. The southern strip shown by Pescott (1968) is now discontinuous, replaced by *Carpobrotus* or grassland, but he did note the occurrence of dead *Senecio* and bare earth on the northern part of the west coast. In 1978-1979 isolated areas on the eastern coast were dominated by *Senecio*, and the species was associated, in part at least, with the distribution of breeding colonies of Short-tailed Shearwaters (cf. Figs. 1 and 3). In January 1979 plants in these areas had been trampled, many had died and were partly broken and covered with soil excavated by shearwaters. In contrast *Senecio* plants outside the bird colonies were still flowering and showing vigorous growth. Plant heights within these colonies were generally higher (0.2- 0.3 m) than those outside, but the plants near cliff tops were usually less than 0.05 m high. Soil depth in *Senecio*-dominated shearwater colonies averaged 0.37 m, whilst in other non-burrowed

areas it was considerably less and plants occasionally grew from boulder crevices across bare rock.

#### 4. SUCCULENT HERBFIELD

Generally the succulent *Carpobrotus rossii* formed a dense (to 95%) low cover, particularly on the more exposed south and southwest cliff tops. However, varying amounts of bare earth, exposed pebbles and wind-eroded boulders occurred. Soil depth was minimal throughout most of the community but in shearwater colonies soil depth exceeded 0.35 m. Plants within the colonies were usually taller (0.13- 0.25 m) than those outside (0.08- 0.12 m).

*Carpobrotus* was usually the only species present but in some areas, particularly along the southeastern coast, *Apium prostratum* was locally dominant (sometimes this was the only plant present, covering some 20-30% of otherwise bare earth). These areas were apparently remnants of the more extensive *Apium* community which covered about 3.3 ha in 1936 (Edmonds 1937); *Carpobrotus* had replaced the *Apium*.





PLATE 18

*Senecio* community, with exposed soil and boulders, burrowed by Short-tailed Shearwaters and extending into a *Pteridium* community. North-western side, Lady Julia Percy Island, January 1979.

Heights of individual *Apium* plants increased from the cliff edge inland (to about 0.15 m), as did their robustness.

The *Carpobrotus* community, which also included *Anagallis arvensis* and *Senecio lautus*, and occasional *Carduus tenuiflorus*, occupied approximately 14.3 ha in 1978 compared with about 9.4 ha in 1936 (Edmonds 1937), and was more extensive than indicated by Pescott (1968).

The swamp noted by Edmonds (1937) was not recognisable in late 1978, the area being incorporated into the grassland community. However, in November 1978 water filled a depression to the southeast of Dinghy Cove; this was dry in January 1979, and no associated vegetation had developed in the very thin layer of soil overlying bedrock.

#### GENERAL COMMENTS ON VEGETATION

The vascular plants recorded on Lady Julia Percy Island are listed in Appendix 1. Although most

communities recorded by Edmonds (1937) were still recognisable in 1978-1979 their distribution had changed. During the same period there has been an increase in both the numbers of species recorded, and the proportion of aliens included. In 1960, about 31% of the species recorded were aliens (Beaglehole 1962) compared with 23.5% in 1936 (Patton 1937) and the 40% recorded in 1978-1979. There have now been 100 species of flowering plants from 34 families recorded on the island and of these 35 are aliens.

More than a half (19) of the 35 alien species are grasses or composites and their colonisation may well be related to the frequent visits by rabbits, the possible importation of stock food, and the unstable environment resulting from soil disturbance caused by both rabbits and burrowing seabirds. In addition there could be seed dispersal by wind. The latter may allow temporary invasion by ephemeral species, which rarely become well established, but they, and other species, may be advantaged by variations in seasonal condi-



tions. The depauperate native grass flora (4 of 18), the absence of *Danthonia*, *Stipa teretifolia* and *Poa poiformis* is surprising, since these species are found on other Victorian islands (see Gillham 1960). The few native species of Poaceae may reflect the absence of natural (mammalian) dispersal agents whereas the introduced grasses probably arrived by the agency of man.

Our record of few shrub species present on the island (*Alyxia buxifolia*, *Lycium ferocissimum*, *Solanum laciniatum*) and the restriction of the first two to cliff faces is in contrast with the earlier but inconclusive reports of thick scrub and dense tea-tree (Mahony 1937). Indeed, it is doubtful whether shrub species, other than the three recently recorded, ever existed on the island. In general soils are too fertile, shallow or

seasonally dry to allow the extensive development of a tea-tree (*Leptospermum* spp.) community, or to sustain other possible species (called tea-tree by the earlier observers). Opportunities for relict representation on cliff faces are few, since there is little soil and most of the higher reaches, at least, are grazed by rabbits. In general the cliff flora is restricted to *Carpobrotus rosii*, *Salicornia quinqueflora*, *Lepidium foliosum*, *Chenopodium murale*, *Cotula australis*, *Spergularia media*, *Polycarpon tetraphyllum*, *Sonchus asper* and *S. oleraceus*, and *Enchylaena tomentosa*. Vigorous stands of *Asplenium obtusatum* also occur.

Transects taken through the major plant communities are summarized in Fig. 2, where percentage cover for the main species is given for 10 m intervals. Results from the transect indicate the complex nature

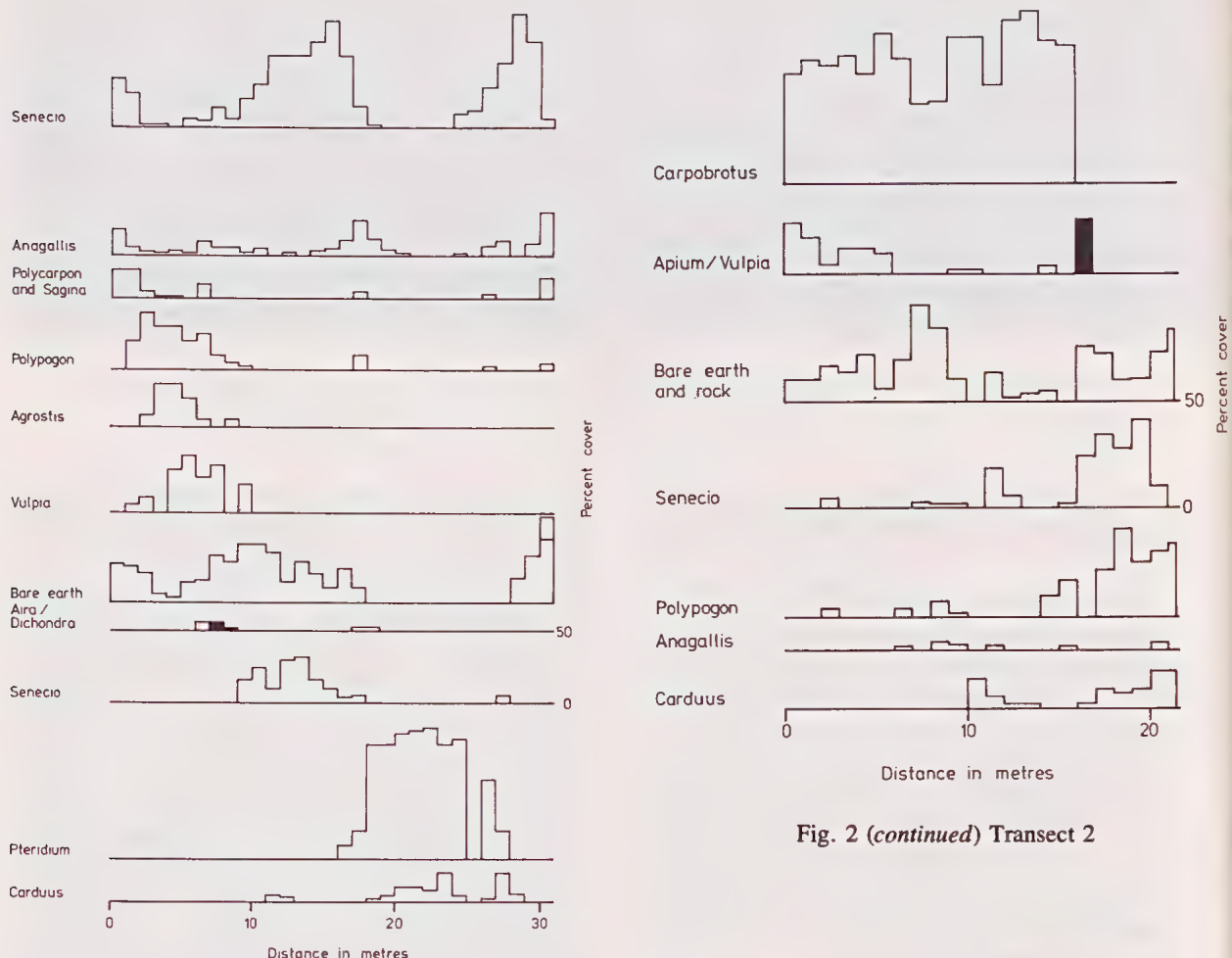


Fig. 2 (continued) Transect 2

Fig. 2—Line transects (10 m intervals); routes shown in Fig. 1. Transect 1 = 312 m, 2 = 212 m, 3 = 390 m. (Major species only shown). Above, Transect 1.

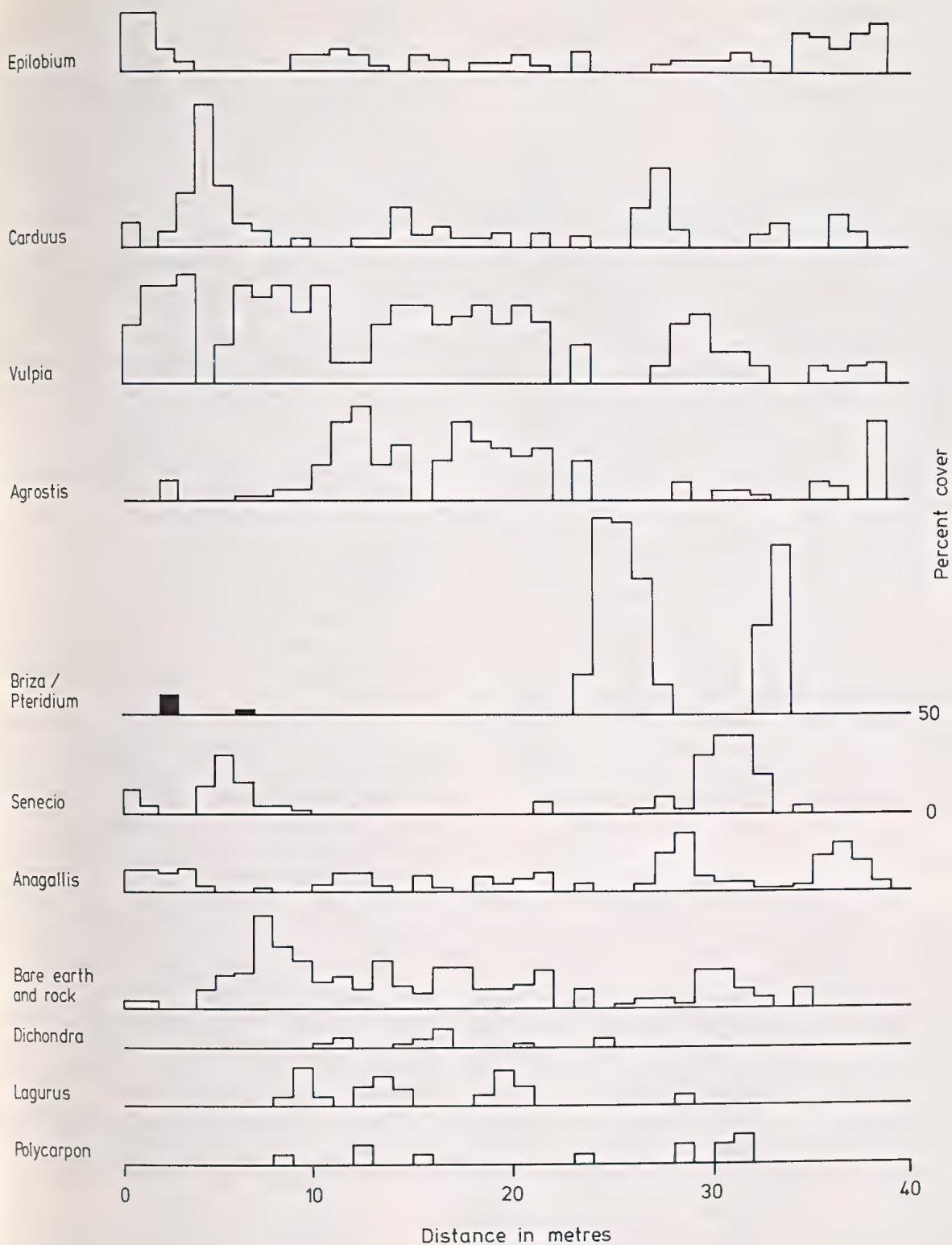


Fig. 2 (Continued) Transect 3



of the grassland community, the few plants associated with *Pteridium*, and the frequent occurrence of bare earth or rocks. In November 1978 the area of bare ground was about 9.3 ha.

## RABBITS

A pair of rabbits was introduced on to the island in 1868. The species was abundant in 1886 (Mahony 1937) and by 1905 the island was honeycombed with warrens (Ingram 1907). In December 1935, 850 pairs were taken by trappers and the rabbit population was high in January 1936 (Tubb & Brazenor 1937). The island was a 'moving mass' of rabbits in 1936 (Beaughlehole 1962), and by 1948 some trappers were taking 4000-6000 rabbits per year (Chappel 1948) and others trapped between 2,500-4,000 in two weeks (Dyson 1948). Rabbits were still numerous in 1949, and trappers caught 1,000 pairs in June (Tarr 1954a). Myxomatosis was present in the late 1950's and extremely few rabbits were seen in November 1960 (Beaughlehole 1962), although trappers had introduced more from the mainland (McKean 1961). The rabbits were increasing in 1962 (McKean 1962), and were in 'enormous numbers' by December 1963 when many were dying of starvation, and 'swarms' were existing on pigface (Pescott 1965). Subsequent visitors have recorded large numbers (Venn 1972, Kelly 1976) and the rabbit flea, infected with myxomatosis, was introduced in October 1976. Numbers were still high in January 1979, but dead and dying rabbits (affected by myxomatosis) were found throughout the island.

## BIRDS

The restricted number and structure of plant communities present on the island have resulted in relatively few land birds being recorded as resident species. In the summer of 1936, the McCoy Society recorded only three native passerines (Welcome Swallow *Hirundo neoxena*, White-fronted Chat *Epthianura albigrons*, and Richard's Pipit *Anthus novaeseelandiae*), and two introduced (House Sparrow *Passer domesticus*, and Common Starling *Sturnus vulgaris*) (Wood Jones & Tubb 1937). Apart from the breeding seabirds (see below) the Society's list also included Red-capped Plover *Charadrius ruficapillus*, Marsh Harrier *Circus aeruginosus*, Peregrine Falcon *Falco peregrinus*, and Australian Kestrel *F. cenchroides* as other breeding species and Eastern Reef Egret *Egretta sacra* and White-faced Heron *Ardea novaehollandiae* as visitors.

Subsequent observers have recorded the species on the island (see Appendix 2) but added only Black Swan *Cygnus atratus*, Sooty Oystercatcher

*Haematopus fuliginosus*, Skylark *Alauda arvensis* and Little Grassbird *Megalurus gramineus* to the list of breeding birds. None of these species were, apparently, present in 1936. Other species have been generally recorded only once, or infrequently. Presumably the paucity of observers, and the restriction of most visits to summer months has also contributed to the reduced total of birds reported from the island, which includes a few trans-Bass Strait migrants.

The populations of seabirds on Lady Julia Percy Island were surveyed in November 1978, and comparison is made below with other recorded details.

## LITTLE PENGUIN *Eudyptula minor*

Wood Jones and Tubb (1937) considered that the species breed mainly 'on the west corner of the island', but some were also nesting under talus boulders at Dinghy Cove, Seal Bay and McCoy Platform which appear to be the only landing places for this species. Tarr (1954a) and Pescott (1965) also found breeding penguins at these sites, but noted that they went 'over the top of the island for at least a quarter of a mile'. McKean (1962) considered that the island was the largest nesting area in Victoria with some 5,000-10,000 pairs breeding there. This estimate was repeated in Pescott (1976) but Reilly (1977) considered that there were some 1,260 pairs in Dinghy Cove and Seal Bay.

In 1978 the most obvious and dense penguin colonies were in the talus slopes of Dinghy Cove (234 burrows) and Seal Bay (117). In addition a low-density breeding area was found behind Seal Bay on the headland. This colony, which extends into the westernmost shearwater colony (see Fig. 3), was estimated at 1,600 burrows using mean density and extrapolated area (about 15 ha). A total of about 2,000 penguin burrows was estimated for the island and thus in 1978 both the population size, and the breeding areas, were considerably lower than those indicated by Pescott (1976).

During our visit in November 1978, 49 burrows were checked to provide occupancy data. Of these 22 were empty, 9 had cold deserted eggs, solitary adults were in 7, 4 had an adult with one egg, 3 had an adult and two eggs, and young were present in a further 4. Such data may not, however, be used to provide population estimates since the species has an extended breeding season (Reilly & Balmford 1975).

## FAIRY PRION *Pachyptula turtur*

The talus slope boulders in Dinghy Cove were the only breeding sites recorded by Wood Jones and Tubb (1937), and Wood Jones (1937) noted that no prions were 'detected on the island plateau . . . where abundant suitable sites were available'. Wood Jones felt that, whilst the penguin and shearwater might cope

with rabbits, the prions could be restricted by them, and therefore nested only under boulders. However, Tarr (1954a) found prions on the east side in burrows on the island's top and, mostly, under pigface. McKean (1962) thought that there were thousands of breeding pairs but Pescott (1976) estimated only some 500 pairs.

No attempt was made to estimate numbers of burrows during our survey. However, the distribution of nests and birds observed (Fig. 3) shows that birds were present, and perhaps nested, in more extensive areas than indicated by Pescott (1976). The species may, indeed, nest around most of the island, though the burrows of this species could not be distinguished from those of the diving-petrel. The island's popula-

tion, probably thousands, may be one of the larger Australian colonies.

#### SHORT-TAILED SHEARWATER *Puffinus tenuirostris*

According to Wood Jones and Tubb (1937) there were two large breeding areas in 1936, but Tarr (1954a) considered that the birds nested 'all over [the island]', keeping mainly towards the higher edges'. McKean (1962) thought that the island held the largest colony in Victoria, and Wheeler (1965), who stated that nesting areas were found 'right round the island, some extending as far as four hundred yards in from the cliff-tops', considered that 90,000 was a conservative estimate of the number of burrows.

The distribution of burrows found in 1978 is

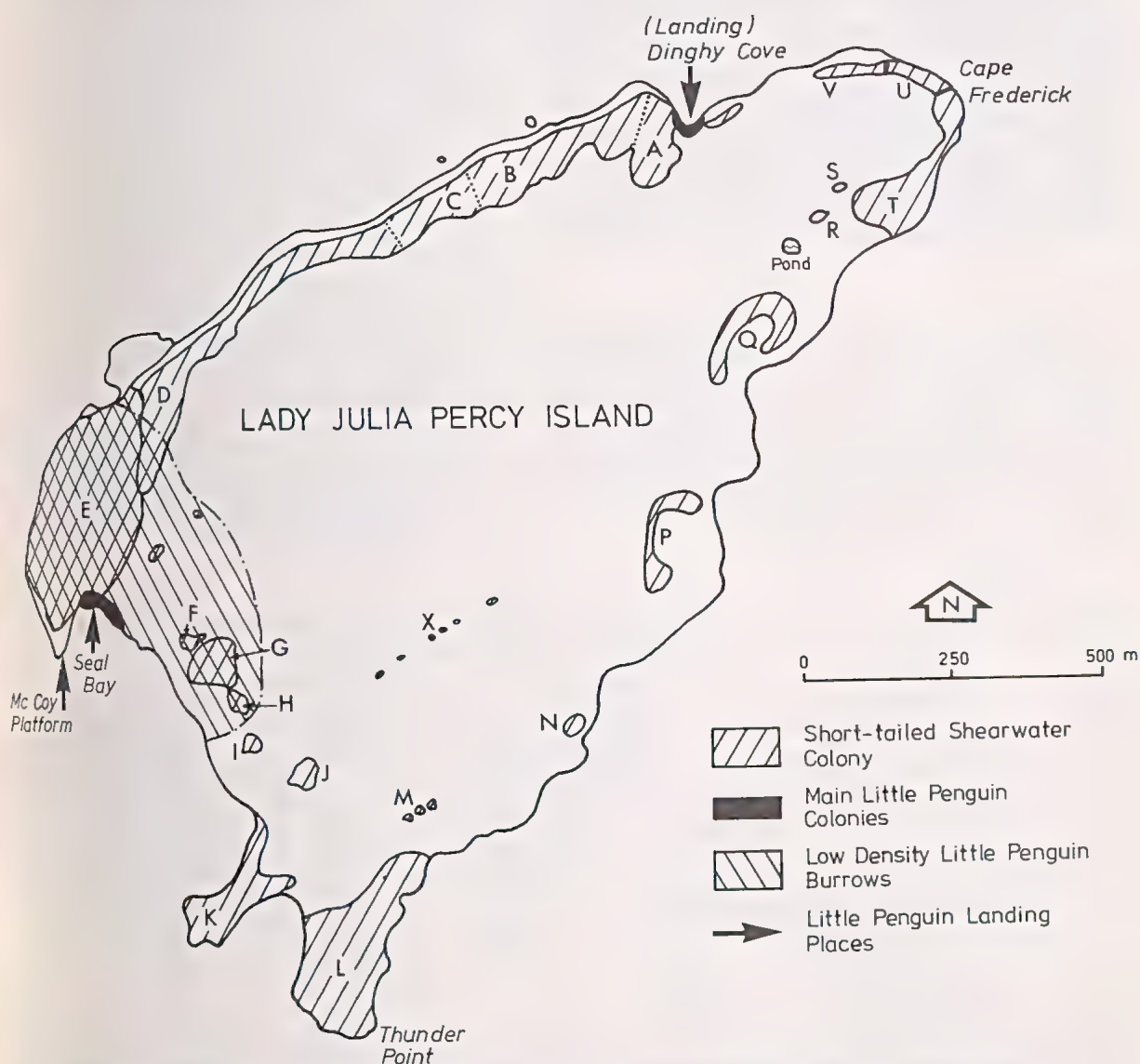


Fig. 3—Distribution of breeding areas of Little Penguin and Short-tailed Shearwater, Lady Julia Percy Island, November 1978.



shown in Fig. 3. Nesting areas did not extend completely around the island, and only on the western corner did burrows extend far inland (A . . . X in Fig. 3). By extrapolation of burrow density, obtained in quadrats of 20 m<sup>2</sup>, and direct counts, an estimate of between 13,100 and 17,400 burrows ( $p = 0.05$ ) was obtained for the island (see Table 1). Colonies were more discrete, and less extensive, than those indicated by Pescott (1976).

During our visits many shearwater burrows were found in shallow soil. Many eggs had been laid on the surface, or under patches of *Carpobrotus*: such eggs were deserted, and by January had disappeared.

COMMON DIVING-PETREL *Pelecanoides urinatrix*

Wood Jones and Tubb (1937) found diving-petrels in and around the boulders on the talus slopes of Dinghy Cove and Tarr (1954b) also recorded them in burrows on the top of the island. Pescott (1976) showed an extensive distribution of nesting area for prion and diving-petrel combined, whilst we were able to confirm nesting in five areas in 1978 (see Fig. 4). Diving-petrels were calling in flight, and landing in and around Dinghy Cove in January 1979, even though all young found in December 1978 were near fledging.

DISCUSSION

There are few plant communities on Lady Julia Percy Island, one of the larger Victorian off-shore islands. Though many species of flowering plants have been recorded a shrub flora is absent and, indeed, may never have existed (cf. Grant 1803, Baudin c. 1801-7, with Mahony 1937). Those conducting the earliest botanical survey of the island (Edmonds 1937, Patton

1937) found no evidence of a shrub community, nor did they expect one. Reports of a tea-tree or scrub may have referred to other woody perennials, rather than *Melaleuca* or *Leptospermum*; either group may have been fired and reduced by sealers, rabbits, guano workers, aborigines (the island was a totem centre, Massola 1968, Gill & West 1971), or more casual visitors. These, together with rabbits and stock, could have reduced regeneration to the point where no shrub cover was present in 1936 (Edmonds 1937). Several visitors to the island have related severe erosion to increases in the rabbit population, but the inter-relationship between the vegetation, breeding seabirds and rabbits has not been studied. (Nor indeed has the local influence of fur seals *Arctocephalus pusillus* on vegetation around and above Seal Bay been examined.) The structurally and floristically simple plant communities now found on Lady Julia Percy presumably reflect the interactions of a relatively harsh environment, edaphic parameters and the biotic influence of grazing, trampling, burrowing and manuring by rabbits, penguins and shearwaters. The volcanic origin of the island may have restricted the range of species colonizing. The success of alien species may have been enhanced by selective grazing by rabbits and the absence of dispersive agents for some of the native species. Additionally, adverse seasonal conditions may modify both the abundance of the plant species and the influence of rabbits on them. Certainly a reduction in the number of rabbits may lead to re-vegetation of an eroded area (and an increase in areas occupied by breeding shearwaters) but vegetation within colonies of shearwaters, and at take-off points, may be temporarily destroyed as a direct consequence of the birds

TABLE 1  
ESTIMATES OF NUMBERS OF SHORT-TAILED SHEARWATER BURROWS ON LADY JULIA PERCY ISLAND, NOVEMBER 1978.  
(COLONIES LISTED ARE LOCATED IN FIG. 4.)

Colony	Area	No. of 20 m <sup>2</sup> quadrats	Burrow density/m <sup>2</sup>		Estimated burrow total	
			Mean	S.E.	Mean	Range
A	0.84	30	0.197	0.016	1650	1380-1920
B.	2.05	30	0.135	0.016	2770	2130-3410
C	0.90	20	0.105	0.013	940	700-1100
D	2.92	30	0.060	0.013	1750	1000-2500
E	6.85	count in 0.17ha	—	—	2165	—
F	0.12	14	0.061	0.013	70	40-110
G	0.56	30	0.167	0.017	940	40-1130
K	1.44	count	—	—	490	—
L	3.61	count	—	—	810	—
T	0.18	25	0.170	0.020	310	230-380
Others		various	—	—	3400	3350-3450
Totals					c. 15300	13100-17400

burrowing and trampling (Gillham 1960, 1961, Norman 1970). This destruction, which may allow invasion by ephemerals, may be locally severe and whole colonies of plants may become totally denuded (*Senecio*, for example, dies off completely leaving bare earth). In drought years, and in the presence of rabbits, such areas may become foci for sheet erosion but normally they recover before the next breeding season (Norman 1970).

Edmonds (1937) and Patton (1937) found a relatively high proportion of alien species in the island's flora in 1936, and subsequent collections have shown that this has increased. The lack of tussock-forming species is striking but not attributable to rabbits since the species co-exist with them elsewhere. In the absence of tussock species most shearwater burrows are beneath *Senecio*, *Carpobrotus* and (mostly alien) grassland. The absence of *Cereopsis novae-hollandiae* is also of interest, since the species breeds on islands off Wilsons Promontory (Dorward & Pizzey 1965, Dorward 1967).

The low diversity of life forms shown within the few plant communities present is also reflected by the few non-passerine or passerine species breeding on the island. Although occasional opportunistic nesting

may occur (e.g. Black Swan in 1976) it is unlikely that additional species will breed regularly. The populations of breeding seabirds are unlikely to have been affected by either the possible shrub removal or by the introduction of rabbits. No evidence of previous colony areas has been found and the differences in population estimates of seabirds presumably relate to methods used. Further, there are now few unoccupied areas which would support burrows of either penguin or shearwater. For the Little Penguin and Short-tailed Shearwater, the Island certainly does not represent the largest colony in Victoria (cf. McKean 1962) since islands off Wilsons Promontory and Phillip and Gabo Islands individually maintain many more breeding pairs (Harris and Norman in prep). However, the importance of the Fairy Prion and Common Diving-Petrel populations is less certain since reliable estimates are difficult to make. It may be that Lady Julia Percy Island has the largest colonies in Victoria and thus more attention should be paid to these species, since their Australian breeding range is centred on Bass Strait (Serventy, Serventy & Warham 1971). If a rabbit eradication campaign is pursued, changes in the Island's vegetation and seabird colonies should be monitored.

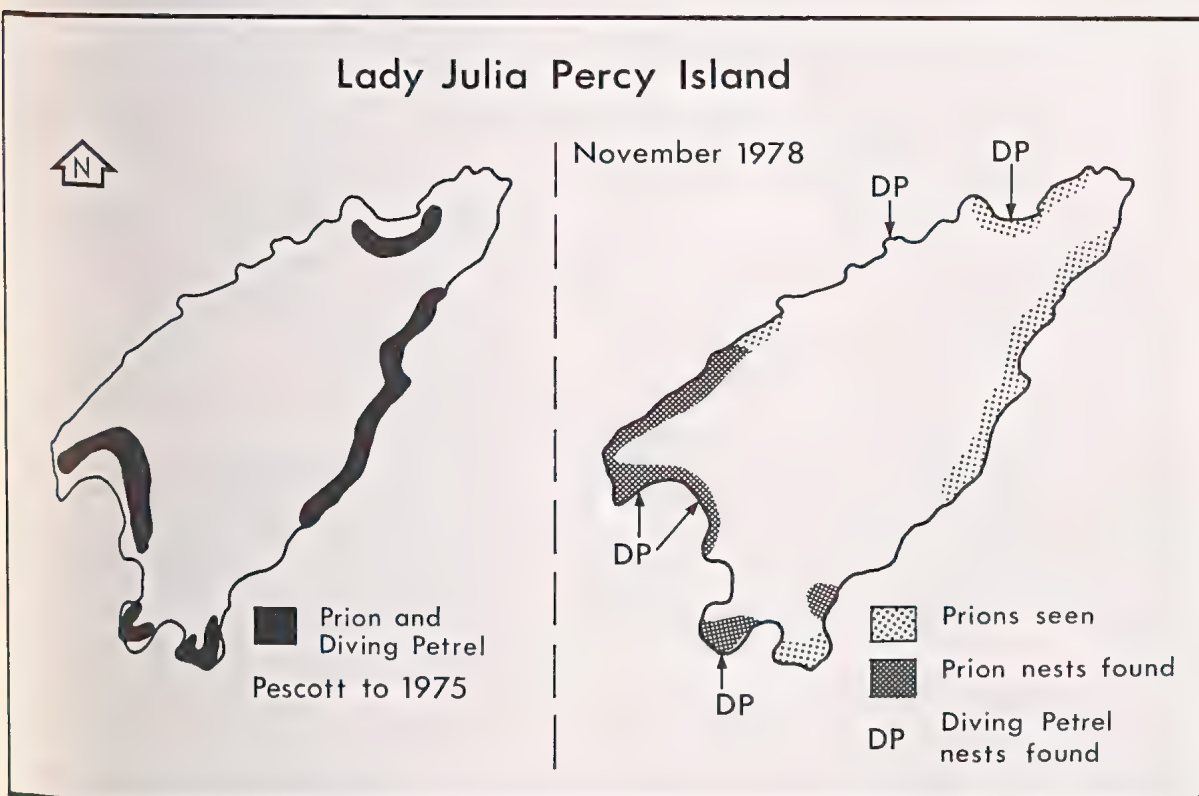


Fig. 4—Distribution of Fairy Prion and Common Diving-Petrel on Lady Julia Percy Island. Comparison is made with an earlier report (Pescott 1976).



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## APPENDIX 1.

Plants recorded from Lady Julia Percy Island by Patton, and Edmonds in 1936 (summer); Beauglehole in 1960 (November); Carr in 1964 (December); Beauglehole and Carr in 1974 (December); and in this survey in 1978 (November) and 1979 (January). Specific nomenclature follows Willis (1970, 1972) as modified by Beauglehole (1978 a, b); Raven and Raven (1976), and Simon (1978); species recorded in brackets denotes assigned dubious records and \* denotes alien species. Voucher specimens of most species are held at the National Herbarium, Melbourne (MEL) or La Trobe University Herbarium (LTB).

Below 1. Patton/Edmonds, 2. Beauglehole, 3. Carr, 4. Beauglehole & Carr 5. This Survey

	1	2	3	4	5
<b>ASPLENIACEAE</b>					
<i>Asplenium obtusatum</i> Forst.f.	X	X	X	X	X
<b>DENNSTAEDTIACEAE</b>					
<i>Pteridium esculentum</i> (Forst.f.) Nakai	X	X	X	X	X
<b>OPHIOGLOSSACEAE</b>					
<i>Ophioglossum coriaceum</i> A. Cunn. in Hook.		X	X		
<b>CENTROLEPIDACEAE</b>					
<i>Aphelia pumilio</i> F. Muell.		X			
<i>Centrolepis polygyna</i> (R.Br.) Hieron.		X		X	
<i>C. strigosa</i> (R.Br.) Roem & Schult.		X	X	X	X
<b>CYPERACEAE</b>					
<i>Cyperus tenellus</i> L.f.		X	X	X	X
<i>Eleocharis acuta</i> R. Br.		X		X	X
<i>Scirpus cernuus</i> Vahl.		X			X
<i>S. marginatus</i> (Thunb.) J. Raynal		X		X	
<i>S. nodosus</i> Rottb.	X	X	X	X	X
<i>S. platycarpus</i> S. T. Blake		X	X	X	
<b>JUNCACEAE</b>					
<i>Juncus bufonius</i> L.	X	X	X	X	X
<i>J. capitatus</i> Weig.*		X			
<i>J. pallidus</i> R.Br.	X	X	X	X	X
<i>J. ?prismatocarpus</i> R.Br.			X		
<b>JUNCAGINACEAE</b>					
<i>Triglochin centrocarpa</i> Hook.		X		X	
<b>LILIACEAE</b>					
<i>Dianella revoluta</i> R.Br.					X
<b>ORCHIDACEAE</b>					
<i>Microtis unifolia</i> (Forst.f.) Reichenb.		X			
<i>Pterostylis? curta</i> R.Br.			X		
<b>POACEAE</b>					
<i>Agrostis avenacea</i> J.F. Gmel.	X	X	X	X	X
<i>Aira caryophyllea</i> L.*	X	X		X	X
<i>Briza minor</i> L.*	X	X	X	X	X
<i>Bromus hordeaceus</i> *			X	X	
<i>B. madritensis</i> L.*		X	X	X	X
<i>Dichelachne crinita</i> (L.f.) Hook.f.	X	X	X	X	X
<i>Distichlis distichophylla</i> (Labill.) Fassett			X		X
<i>Holcus lanatus</i> L.*		X	X	X	X
<i>Hordeum leporinum</i> Link*	X	X	X	X	X
<i>Lagurus ovatus</i> L.*				X	X
<i>Lolium perenne</i> L.*			X		X
<i>Lophochloa cristata</i> (L.) Hylander*		X			
<i>Phalaris minor</i> Retz.*	X	X	X	X	X
<i>Poa annua</i> L.*		X	X	X	X

## APPENDIX 1 (continued)

	1	2	3	4	5
<i>P. australis</i> sp. agg.	X				
<i>Polypogon maritimus</i> Willd.*		X	X	X	X
<i>Puccinellia stricta</i> (Hook.f.) C. Blom.		X	X	X	X
<i>Vulpia bromoides</i> (L.) S.F. Gray*		X	X	X	X
<i>V. myuros</i> (L.) K.C. Gmel.*			X	X	X
AIZOACEAE					
<i>Carpobrotus rossii</i> (Haw.) Schwantes	X	X	X	X	X
<i>Disphyma clavellatum</i> (Haw.) Chinnock	X		X	X	
APIACEAE					
<i>Apium prostratum</i> Vent.	X	X	X	X	X
<i>Hydrocotyle foveolata</i> Hj. Eichler		X			
<i>H. hirta</i> R.Br.ex A. Rich.		X	X	X	X
APOCYNACEAE					
<i>Alyxia buxifolia</i> R.Br.	X	X	X	X	X
ASTERACEAE					
<i>Calocephalus brownii</i> (Cass.) F. Muell.	X	X	X	X	X
<i>Carduus tenuiflorus</i> Curt.*	X	X	X	X	X
<i>Cirsium vulgare</i> (Savi) Ten.*		X	X	X	X
<i>Cotula australis</i> (Sieber ex Spreng.) Hook.f.		X	X	X	X
<i>C. coronopifolia</i> L.	X	X	X	X	
<i>Gnaphalium gymnocephalum</i> DC.		X	X	X	
<i>G. indutum</i> Hook.f. in Hook.	X				
<i>G. luteo-album</i> L.		X	X	X	X
<i>G. sphaericum</i> Willd.				X	
<i>Leontodon taraxacoides</i> (Vill.) Merat*		X		X	
<i>Senecio laevis</i> Forst.f.ex. Willd.	X	X	X	X	X
<i>Sonchus asper</i> (L.) Hill*		X	X	X	X
<i>S. oleraceus</i> L.*				X	X
BORAGINACEAE					
<i>Myosotis australis</i> R.Br.		X	X	X	
BRASSICACEAE					
<i>Lepidium foliosum</i> Desv.	X	X	X	X	X
CAMPANULACEAE					
<i>Wahlenbergia quadrifida</i> (R.Br.) Alph.DC.		X		X	
CARYOPHYLLACEAE					
<i>Cerastium glomeratum</i> Thuill.*		X	X	X	X
<i>Polycarpon tetraphyllum</i> (L.) L.*	X	X	X	X	X
<i>Sagina apetala</i> Ard.	X	X	X	X	
<i>S. procumbens</i> L.		X	X	X	X
<i>Silene gallica</i> L.*		X	X	X	
<i>Spergularia media</i> (L.) C. Presl.		X	X	X	X
<i>S. rubra</i> (L.) J. & C. Presl.	X				
<i>Stellaria media</i> (L.) Cyrillo*		X			
CHENOPODIACEAE					
<i>Chenopodium glaucum</i> L.	X	X	X	X	X
<i>C. murale</i> L.*		X	X	X	X
<i>Enchylaena tomentosa</i> R.Br.	X	X	X	X	X
<i>Rhagodia baccata</i> (Labill.) Moq.	X		X	X	
<i>Salicornia quinqueflora</i> Bung. ex Ung-Stern.	X	X	X	X	X
CONVOLVULACEAE					
<i>Dichondra repens</i> Forst. & Forst.f.	X	X	X	X	X
CRASSULACEAE					
<i>Crassula macrantha</i> (Hook.f.) Diels & Pritzel		X			
<i>C. purpurata</i> (Hook.f.) Domin.		X		X	X
<i>C. sieberana</i> (Schult. & Schult.f.) Druce		X	X	X	



## APPENDIX 1 (continued)

	1	2	3	4	5
ELATINACEAE					
<i>Elatine gratioloides</i> A. Cunn.		X		X	
FABACEAE					
<i>Trifolium cernuum</i> Brot.*		X	X	X	X
<i>Trigonella ornithopodioides</i> (L.) Lam. & DC.*		X		X	
GENTIANACEAE					
<i>Centaurium spicatum</i> (L.) Fritsh	X	sp.		sp.	X
<i>Cicendia filiformis</i> (L.) Delarbre*		X			
<i>Sebaea ovato</i> (Labill.) R.Br.		X	X	X	
GERANIACEAE					
<i>Erodium cicutarium</i> (L.) L'Herit. ex Ait.*		X			
<i>Geranium solanderi</i> R.C. Carolin		X		X	X
<i>Pelargonium australe</i> Willd.	X	X	X	X	
LOBELIACEAE					
<i>Pratia platycalyx</i> (F. Muell.) Benth.		X		X	
LOGANIACEAE					
<i>Mitrasacme paradoxa</i> R.Br.		X			
ONAGRACEAE					
<i>Epilobium billardierianum</i> Ser. ex.DC.	X	X	X	X	X
OXALIDACEAE					
<i>Oxalis corniculata</i> L.		X	X	X	X
POLYGONACEAE					
<i>Rumex brownii</i> Campd.		X	X	X	X
PRIMULACEAE					
<i>Anagallis arvensis</i> L.*	X	X	X	X	X
<i>Samolus minima</i> (L.) Krause*		X		X	
<i>S. repens</i> (Forst. & Forst.f.)			X	X	
RANUNCULACEAE					
<i>Ranunculus sessiliflorus</i> R.Br. ex DC		X		X	
RUBIACEAE					
<i>Galium murale</i> (L.) All.*		X	X	X	X
SCROPHULARIACEAE					
<i>Limosella australis</i> R.Br.		X		X	X
SOLANACEAE					
<i>Lycium ferocissimum</i> Miers*		X	X	X	X
<i>Solanum laciniatum</i> Ait.	(X)	X	X	X	X
<i>S. nigrum</i> L.*		X	X	X	
STYLIDIACEAE					
<i>Stylidium inundatum</i> R.Br.		X	X	X	
URTICACEAE					
<i>Parietaria debilis</i> Forst.f.		X		X	X
<i>Urtica urens</i> L. *	X	X	X	X	X

## APPENDIX 2.

## SUMMARY OF BIRDS RECORDED ON LADY JULIA PERCY ISLAND.

(Nomenclature follows Royal Australasian Ornithologists Union 1978. See references.)

- Fiordland Penguin *Eudyptes pachyrhynchus*  
One moulting bird January 1979.
- Erect-crested Penguin *Eudyptes sclateri*  
Recorded from island (Learmonth 1952).
- Little Penguin *Eudyptula minor*  
Breeding species, population estimated at about 2,000 occupied burrows in 1978. (See above for further details).
- Fairy Prion *Pachyptula turtur*  
Breeding species, mainly in talus slopes around Dinghy Cove and Seal Bay. Population estimated at 'thousands of pairs' (McKean 1962) or 500 pairs (Pescott 1976), and thousands of pairs in 1978.
- Short-tailed Shearwater *Puffinus tenuirostris*  
Breeding species, population estimated at between 13,100-17,400 in 1978. (See above for further details).
- Common Diving-Petrel *Pelecanoides urinatrix*  
Breeding species mainly in talus slopes. 'Comparatively sizeable numbers' (McKean 1962).
- Black-faced Shag *Leucocarbo fuscescens*  
Infrequently recorded.
- Pied Cormorant *Phalacrocorax varius*  
Very infrequent visitor.
- Little Pied Cormorant *Phalacrocorax melanoleucos*  
Very infrequent visitor.
- White-faced Heron *Ardea novaehollandiae*  
A few birds recorded by most observers.
- Eastern Reef Egret *Egretta sacra*  
Recorded by Wood Jones and Tubb (1937) but not subsequently.
- Black Swan *Cygnus atratus*  
Nest recorded in 1976 (P. C. Kelly).
- Australian Shelduck *Tadorna tadornoides*  
Pair present in July 1970 (R. M. Warneke, Pers. comm.) and in November 1978.
- Whistling Kite *Haliastur sphenurus*  
Recorded once, by Tarr (1954b).
- White-bellied Sea-eagle *Haliaeetus leucogaster*  
One seen in January 1978 (K. Norris, pers. comm.).
- Marsh Harrier *Circus aeruginosus*  
Breeding species, with six nests in 1978, and a maximum of 18 birds recorded in 1975 (G. E. Cerini). Feeds on rabbits and shearwaters.
- Peregrine Falcon *Falco peregrinus*  
Breeding species, maximum of five birds seen (Tarr 1954b), seen feeding on prions and Short-tailed Shearwaters.
- Brown Falcon *Falco berigora*  
Two birds recorded in 1964 (Wheeler 1965) and in 1978.
- Australian Kestrel *Falco cenchoides*  
Usually one pair present.
- Stubble Quail *Coturnix novaezelandiae*  
A few birds recorded in 1949 (Tarr 1954a) and 1964 (Wheeler 1965).
- Sooty Oystercatcher *Haematopus fuliginosus*  
Two-three pairs breed.
- Masked Lapwing *Vanellus miles*  
Recorded by Tarr (1954b), and by R. M. Warneke in July 1970 and January 1976.
- Red-capped Plover *Charadrius ruficapillus*  
Only record, as a breeding species, by Wood Jones and Tubbs (1937).
- Black-fronted Plover *Charadrius melanops*  
Recorded by A. C. Beaglehole in 1974.
- Silver Gull *Larus novaehollandiae*  
Frequently recorded (maximum 50) roosting on island.
- Pacific Gull *Larus pacificus*  
Occasional records.
- Arctic Tern *Sterna paradisaea*  
One found dead on island (Wheeler 1965).
- Crested Tern *Sterna bergii*  
Occasionally recorded on rocks around island.
- Eastern Rosella *Platycercus eximius*  
One dead young found in 1964 (Pescott 1965).
- Blue-winged Parrot *Neophema chrysostoma*  
Recorded by Tarr (1954b).
- Fan-tailed Cuckoo *Cacomantis pyrrhophanus*  
Seen by Beaglehole in December 1974.
- Barn Owl *Tyto alba*  
Occasionally recorded, with a maximum of seven in



APPENDIX 2 (*continued*)

July 1970. These have been seen feeding on diving-petrels (R. M. Warneke, Pers. comm.).

Skylark *Alauda arvensis*

Now plentiful and nesting but not recorded by Wood Jones and Tubb (1937).

Richard's Pipit *Anthus novaehollandiae*

A common breeding species.

Welcome Swallow *Hirundo neoxena*

Breeding species using caves for nest sites.

Fairy Martin *Petrochelidon ariel*

Beaglehole recorded this species nesting in small numbers, December 1974.

White-winged Triller *Lalage sueurii*

One male seen in November 1978.

Grey Shrike-Thrush *Colluricincla harmonica*

One seen in November 1978.

Satin Flycatcher *Myiagra cyanoleuca*

A male seen in 1949 (Tarr 1954b).

Little Grassbird *Megalurus gramineus*

First recorded in 1960 by McKean (1961), now is moderately common and presumably breeds.

White-fronted Chat *Ephthianura albifrons*

Breeding species with about 100 present in 1973 and in 1978.

European Goldfinch *Carduelis carduelis*

Occasional birds recorded.

House Sparrow *Passer domesticus*

Small numbers have bred, recorded from Wood Jones and Tubb (1937) onwards.

Common Starling *Sturnus vulgaris*

A breeding species, using cliffs, with counts of 75-100 birds.

Australian Magpie *Gymnorhina tibicen*

Recorded only in July 1970 (R. M. Warneke, Pers. comm.).

## SOME AUSTRALIAN LATE CAINOZOIC ECHINOIDS

By R. J. FOSTER\* AND G. M. PHILIP\*\*

ABSTRACT: Late Cainozoic echinoids described and illustrated from various localities in Western Australia, South Australia and Victoria include the living species *Amblypneustes formosus* Valenciennes, *Microcyphus annulatus* Mortensen and *Peronella orbicularis* (Leske). The Pliocene species *Arachnoides incisa* Tate is referred to *Fellaster* and is recorded from the Werrikooian of Victoria. *Amblypneustes* sp. nov. occurs in the ?early Pleistocene Roe Calcarene of Western Australia. These records indicate the replacement of the diverse older Cainozoic echinoid fauna with some modern forms from the Pliocene onwards.

This paper describes available echinoids from various Pliocene and Pleistocene localities in Western Australia, South Australia and Victoria and represented in various museums. Although only temnopleurids and clypeasteroids are present in the material so far discovered, it is judged to be sufficiently representative to justify general observations on the fauna.

The widespread mid-Tertiary bryozoal lime grainstones of southern Australia contain a remarkably prolific and characteristic echinoid fauna which bears little close comparison with the Australian echinoid fauna of today if cosmopolitan spatangoids such as *Schizaster* are excluded from consideration. By late Pliocene times marine sedimentation was far more restricted and usually of a clastic character. Echinoids recovered from these late Tertiary strata are few in number, but are modern in their relationships. Although some characteristic living Australian genera appear first in the Oligocene or early Miocene (e.g. *Phyllacanthus*, Philip 1963, p. 202; *Goniocidaris*, Philip 1964, p. 449; *Heliocidaris*, Philip 1965, p. 191), from the available record it appears as if the mid-Tertiary fauna was largely replaced in the late Miocene and Pliocene, and by the early Pleistocene the modern fauna was fully established. *Pseudechinus* appeared in the late Miocene as did the characteristic living littoral New Zealand genus *Evechinus* (Philip 1969, p. 233, p. 268). The early Pliocene saw the appearance of *Fellaster* with the species *F. incisa* (Tate) which extends upwards into the early Pleistocene. The mid Pliocene Hallett Cave Sandstone contains the species *Goniocidaris tubaria hallettensis* Philip, a subspecies of the living form, together with *Peronella platymodes* (Tate) which is probably a fore-

runner of the living species *Peronella orbicularis* (Leske). By the Pleistocene this latter species had appeared, together with the living temnopleurids *Amblypneustes formosus* Valenciennes and *Microcyphus annulatus* Mortensen. These temnopleurids belong to the group with pitted sutures; all of the older temnopleurids are sculptured.

This incomplete record seems to indicate that although the origin of some components is in the older Tertiary faunas, the living echinoid fauna consists mainly of immigrants from the Indo-Pacific region that appeared in the Australian sequences from the Pliocene onwards.

Material described herein is lodged in the collections of the National Museum, Victoria (NMV) the Department of Geology, University of Sydney (SU) and the Western Australian Museum, Perth (WAM).

## SYSTEMATICS

## ORDER CLYPEASTEROIDA A. Agassiz

## FAMILY ARACHNOIDIDAE Duncan

Genus *Fellaster* Durham

*Fellaster* Durham 1955, pp. 125-126, fig. 29b; Durham 1966, p. U464, fig. 358, 2a-c.

DIAGNOSIS: Petals wide, open and raised. Combed areas cover about two-thirds width of ambulacral plates outside the petals; periproct supra-marginal. Oral surface with two or three post-basical coronal interambulacral plates, and one circlet of interambulacral plates meeting around the small, basical coronal circlet.

REMARKS: The genus is separated from *Arachnoides* by the position of the periproct which is more anterior, the absence of a periproctal groove and the extension of two or three

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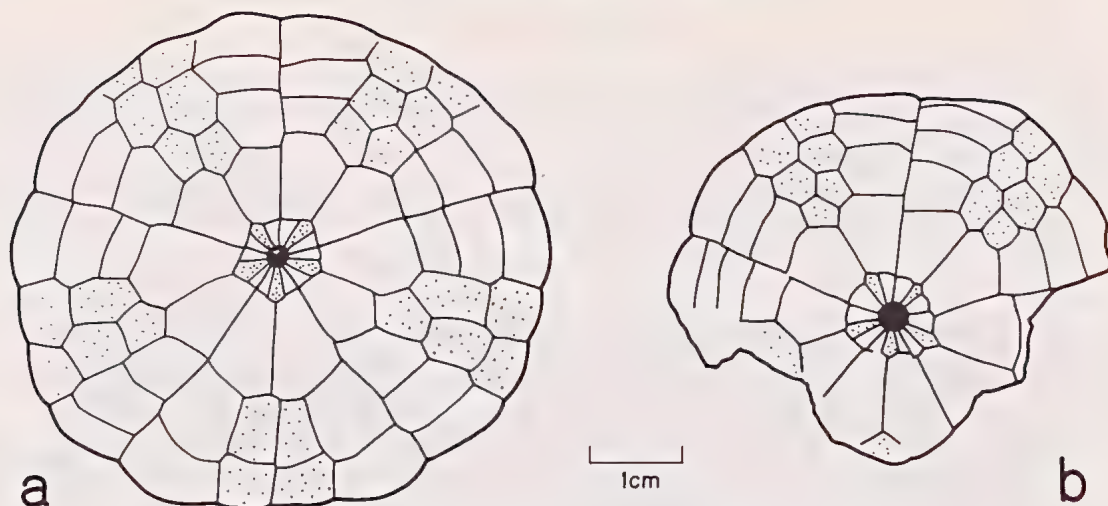


Fig. 1. Plating of adoral surface of *Arachnoides incisa* (Tate). (a) NMV P55478, Red Bluff, early Pliocene; (b) NMV P55480, Werrikoo, Pleistocene.

interambulacral plates onto the oral surface. Previously, the genus has been monotypic and known only from New Zealand in *F. zelandiae* (Gray), a common littoral echinoid. Farquhar (1894) recorded this species as occurring in the Pliocene of Wanganui. However, Fell (1953, p. 254) notes 'A mid-Pliocene New Zealand species much resembles a species still found in Recent Queensland waters', suggesting rather a relationship of this form with *Arachnoides placenta* (Linn.). No material of the New Zealand Pliocene form is at present available for study.

***Fellaster incisa* (Tate)**

(Pl. 20, fig. 4, 6-7; Fig. 1)

*Arachnoides incisa* Tate 1893, p. 192, pl. 13, fig. 3; H. L. Clark 1946, p. 340.

**DIAGNOSIS:** A species of *Fellaster* with well defined ambital ambulacral indentations.

**MATERIAL AND OCCURRENCE:** The holotype, the specimen figured by Tate, is AUGD T359, Red Bluff, Lake Tyers, Gippsland, from the Jemmys Point Formation of Early Pliocene age. A topotype specimen (NMV P55478) is illustrated in Pl. 20, fig. 7; Fig. 1a. The Pleistocene specimens (NMV P55479-554780) are from Allot. 73B, Parish of Werrikoo, "Bankivia Beds" (ex F. A. Singleton collection).

**REMARKS:** This species is extremely close to *F. zelandiae*, seeming to differ solely in the presence of ambital indentations. Although the Pleistocene material is fragmentary, one of the specimens shows well this characteristic.

**FAMILY LAGANIDAE Desor**

**Genus *Peronella* Gray**

*Peronella* Gray 1855, p. 13; Mortensen 1948, p. 286 *et seq.*; Durham 1955, pp. 139-141; Durham 1966, pp. U473-475.

***Peronella orbicularis* (Leske)**

(Pl. 20, fig. 1-2, 5)

*Echinodiscus orbicularis* Leske 1778, p. 208.

*Peronella orbicularis* (Leske) Mortensen 1948, p. 286 *et seq.* (cum synon.).

**DIAGNOSIS:** A small low species of *Peronella*, rounded to somewhat angular in outline, with comparatively large pointed petals and with flat or concave oral surface. Margin of the test usually thickened.

**MATERIAL AND OCCURRENCE:** Forty specimens (WAM 9037/46 and SU F21767-8) from the Carnarvon Basin appear to have been derived from the Exmouth Sandstone, being collected from the eastern margin of Lake McLeod between Red Bluff and Cape Cuvier. The illustrated specimens (SU 13317-9) are from the same general locality. ?Early Pleistocene. In addition there are 12 specimens from various localities in the Roe Calcarene.

**REMARKS:** This characteristic species of *Peronella* is at present distributed from the Malaysian region down into tropical Australian waters. According to H. L. Clark (1946) it is found south as far as Cape Upstart, Queensland, and Shark Bay in Western Australia. Mortensen's statement that it occurs as far south as Albany requires verification. It has also been recorded from the upper Miocene of Java although this occurrence is questioned by Mortensen (1948 p. 290).

In specimens from the Carnarvon Basin the test is more fragile and the margin is thinner than in those from the

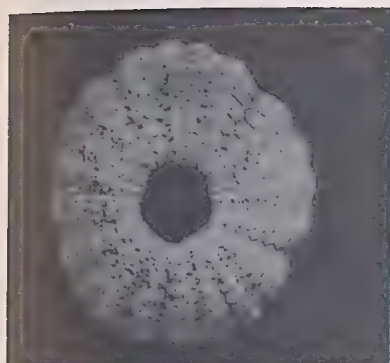
**PLATE 19 (opposite)**

Figures  $\times 2$  unless otherwise stated

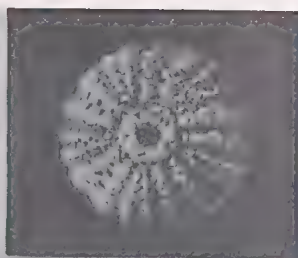
Fig. 1-3 *Microcyphus annulatus* Mortensen. (1) Adoral view of WAM 69.619; (2) Adapical view of SU 13320; (3) Lateral view of NMV P27037. Various localities from the Roe Calcarene, W.A., ?Pleistocene.

Fig. 4 *Amblypneustes* sp. nov. Lateral view of WAM 69.693, W. of Eucla, Western Australia, Roe Calcarene ?Pleistocene.

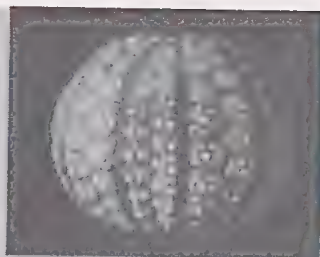
Fig. 5-7 *Amblypneustes formosus* Valenciennes. (5) Lateral view of naked test from St. Vincent Gulf, S. Australia, showing characteristic colour marking,  $\times 3$ ; (6) Lateral view of NMV P27035, Roe Calcarene, ?Pleistocene; (7) Lateral view of SU F181/70, east of Robe, S.A., ?Pleistocene.



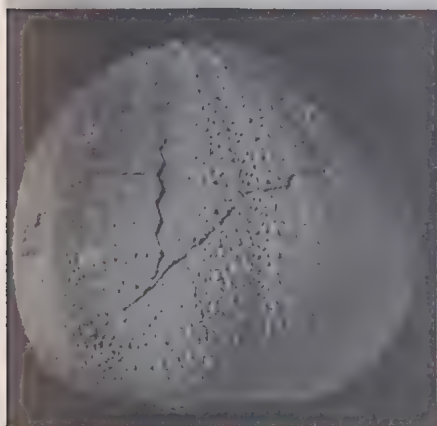
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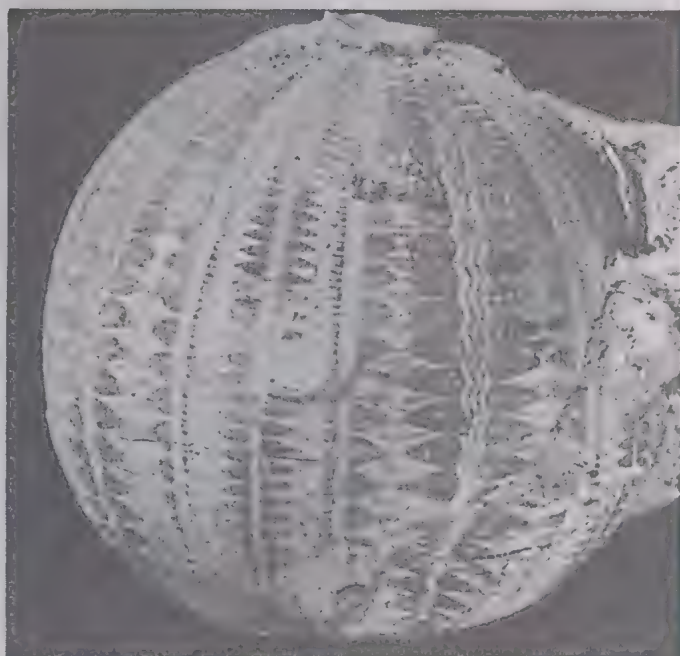
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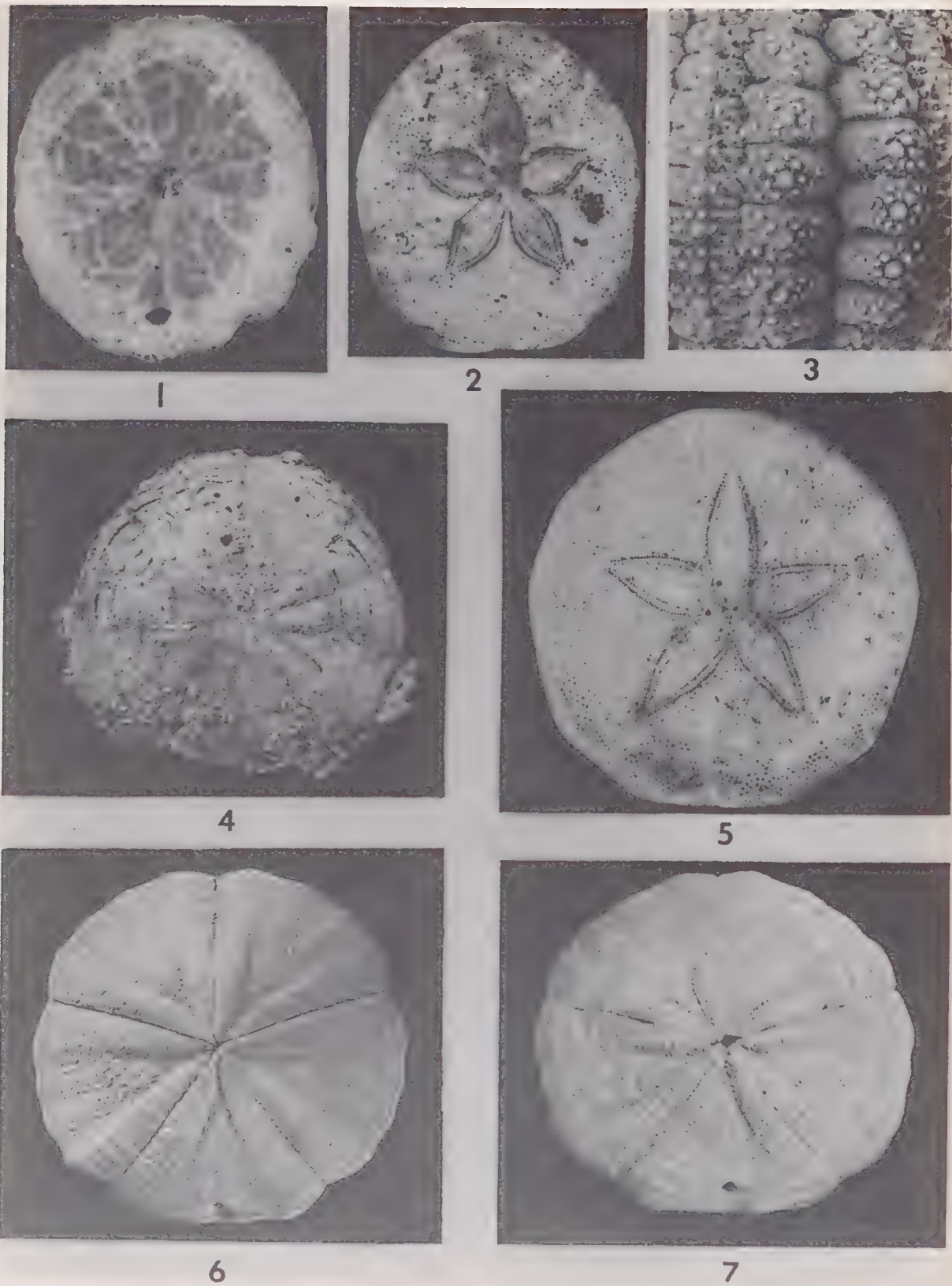


PLATE 20

Roe Calcarene Mortensen (1948, p. 288) described similar variation in living material.

ORDER CAMARODONTA Jackson  
SUBORDER TEMNOLEURINA Mortensen  
FAMILY TEMNOLEURIDAE A. Agassiz

REMARKS: The abundant Australian Tertiary temnoleurids have been revised by Philip (1969, 1971). Those previously described belong to sculptured temnoleurid genera, mostly confined to Tertiary strata in Australia and New Zealand. However, the occurrence of *Pseudechinus* cf. *albocinctus* (Hutton) in the late Miocene of eastern Victoria (Philip 1969, p. 268) points to the Tertiary origin of this living Australian, New Zealand and S. American genus. In terms of the two-fold division proposed by Philip (1969) for the family, the two genera recognized here are temnoleurids with pitted sutures, and so bear no close relationship to the older Tertiary species.

Genus *Amblypneustes* L. Agassiz

*Amblypneustes* L. Agassiz, 1841, p. 7; Mortensen 1943, p. 186 et seq. (cum. synon.).

DIAGNOSIS: Moderate to large-sized temnoleurids with ambulacra somewhat narrower than interambulacra and with one primary tubercle to each compound plate. Pore-pairs of the ambulacra arranged in arcs of three; no widening of the poriferous tract toward the peristome. Primary tubercles faintly crenulated or smooth, similar in size to secondary ones; sutural pores often indistinguishable. Apical system regularly dicyclic; gill slits shallow.

REMARKS: This endemic genus contains some of the most characteristic living Australian echinoids. It differs essentially from *Holopneustes* in the structure of the ambulacra which possess a primary tubercle every second or third compound plate. Geographically *Amblypneustes* ranges from Geraldton to Tasmania and Bass Strait. It is a littoral genus, living in abundance on shallow, grassy bottoms. Often after storms it is washed up in great numbers along southern Australian beaches. Fossil occurrences have not been reported previously.

Although *Amblypneustes* may be readily distinguished from the closely related genus *Holopneustes* in the presence of a primary tubercle on each ambulacral plate, test characters in general do not permit differentiation of the several living species currently recognized. They are distinguished by the nature of the periproctal plates (whether

smooth or tuberculated), the colour and length of the spines, the nature of internal spicules and colour markings of the test, features not usually preserved in fossil material.

*Amblypneustes formosus* Valenciennes  
(Pl. 19, fig. 5-7)

*Amblypneustes formosus* Valenciennes 1846; Mortensen 1943, p. 203 et seq. (cum synon.); H. L. Clark 1946, pp. 317-318.

DIAGNOSIS: A species of *Amblypneustes* with moderately large primary and small secondary tubercles; pore-pairs arcuate but never triserial. Primary interambulacral tubercles separated by a lozenge-shaped dark-brown area; ambulacra with similar, although less well-defined, colour markings. MATERIAL: SU F181/70, "Marine" limestone, Section 32, Hundred of Ross, County Robe, approximately 25 km east of Robe, South Australia (?Pleistocene). A second specimen, NMV P27035, from spoil heap, PMG Tower No. 33, 50 km east of Madura, Western Australia, Roe Calcarene (?Early Pleistocene), is with some slight reservation also referred to this species.

MEASUREMENTS:

	<i>h.d.</i>	<i>v.d.</i>	<i>ambs</i>	<i>inter-ambs</i>
P27035	43 mm	39 mm	c. 44	c. 30
SU F181/70	77 mm	72 mm	c. 53	c. 36

*Amblypneustes* sp. nov.

WAM 69.693 26 mm 21 mm 25 22

REMARKS: Although traces of original colour markings in fossil echinoids are found rarely (e.g., *Ortholophus woodsi* (Laube), Philip 1969, pl. 8, fig. 16) their occurrence in SAF 181/70 is particularly fortunate, for they permit positive identification of the specimen. Although it is not well preserved as to surface detail, it seems that the white areas in the specimen (Pl. 19, fig. 7) have been preferentially weathered and all traces of staining and surface ornamentation have been removed from them. In contrast, in living specimens, it is these areas that are dark brown in colour. In terms of coloration the fossil specimen is therefore in part a photo-negative of a living specimen (Pl. 19, fig. 5). The lozenge-shaped colour markings of *A. formosus* distinguish its test from other species of *Amblypneustes*, in particular *A. pallidus* Lamarck. Although the specimen from the Roe Plains lacks such characteristic colour markings, it is referred to *A. formosus*.

It should be noted that both of the fossil specimens here identified as *A. formosus* are larger than previously recorded living specimens. H. L. Clark (1946, p. 318) mentioned the largest specimen he encountered as one with h.d. of 36 mm. and v.d. of 37 mm. However, both tests conform to the characters of the living species in all other respects.

*Amblypneustes* sp. nov.  
(Pl. 19, fig. 4)

DIAGNOSIS: A species of *Amblypneustes* with narrow ambulacra and high ambulacral plates with erect arcs. Secondary tubercles small and sparse.

MATERIAL: WAM 69.623, 74 km by road west of Eucla

PLATE 20 (opposite)

Figures x2 unless otherwise stated

Fig. 1-2, *Peronella orbicularis* (Leske). (1) Adoral surface of SU 13317, a specimen prepared to show sutures, Carnarvon Basin, ?Pleistocene; (2) Adapical surface of SU 13318; (5) Adapical surface of large specimen SU 13319.

Fig. 3 *Microcyphus annulatus* Mortensen. Enlargement of ambital ornament of WAM 69.619, Roe Calcarene, ?Pleistocene.

Fig. 4, 6-7 *Fellaster incisa* (Tate). (4) Adapical view of NMV P55479, Allot. 73B, Werriook, Victoria, Pleistocene, x1; (6) Adapical view of holotype AUGD T359, Red Bluff, Lake Tyers, Gippsland, Victoria, early Pliocene, x1; (7) Adapical view of NMV P55478 from the same locality.



Motel, south side of Eyre Highway; WAM 69.693, same locality, north side of Eyre Highway, and four other fragmentary specimens, all from the Roe Calcarenite. (?Early Pleistocene).

REMARKS: This species is distinguished from previously described species of *Amblypneustes* by its high ambulacral plates, and narrow ambulacral columns. In *A. pallidus* and *A. formosus* a specimen of dimensions similar to WAM 69.693 has c. 35 amb in each column as opposed to 25 in this species. The faintly crenulated tubercles, sparsely tuberculated ambulacral and interambulacral midzones with ill-defined sutural pits, together with the shallow gill slits, indicate that the species is best referred to *Amblypneustes*. In terms of existing published information it bears no close relationship to any living Australian species.

#### Genus *Microcyphus* L. Agassiz

*Microcyphus* L. Agassiz 1841, p. 8; Mortensen 1943, p. 148 et seq. (cum synon.).

DIAGNOSIS: Small, hemispherical temnopleurids with narrow poriferous tracts and with conspicuous, often sunken median ambulacral and interambulacral zones. Compound ambulacral plates trigeminate, each with a primary ambulacral tubercle. Tubercles smooth or faintly crenulate; apical system regularly dicyclic; gill slits obsolete.

REMARKS: Mortensen (1943) noted that the living southern Australian species *M. zigzag*, *M. annulatus*, *M. composus*, and *M. pulchellus* form a separate group, characterised by the high, egg-shaped, thick test. These features readily distinguish the group from other Indo-Pacific species.

#### *Microcyphus annulatus* Mortensen

(Pl. 19, fig. 1-3)

*Microcyphus annulatus* Mortensen 1904, p. 101; 1943, p. 171 et seq. (cum synon.); H. L. Clark 1946, p. 316.

DIAGNOSIS: A high-tested species of *Microcyphus* with upright ambulacral arcs, so that the ambulacra appear uniserial. Median and horizontal sutures conspicuously deepened, with broad, bare, median midzone.

MATERIAL: Five tests: one from 50 km east of Madura; the remainder from a locality 74 km by road west of Eucla Motel, Eyre Highway, all from the Roe Calcarenite. (?Early Pleistocene).

#### MEASUREMENTS:

	<i>h.d.</i>	<i>v.d.</i>	<i>ambs</i>	<i>interambs</i>	<i>apical system</i>	<i>peristome</i>
NMV						
P27037	16.5	14.0	14(15)	11	24 mm	5 mm
WAM						
69.619	19.0	16.5	20(21)	15(16)	4.5 mm	4.7 mm
WAM						
70.1825	13.5	12	16(17)	13(14)	c.4.5 mm	3.8 mm
WAM						
69.692	13	12	17(18)	13	c.3.5 mm	4.0 mm
SU						
13320	12.0	10.5	14	11(12)	3.5 mm	4.5 mm

REMARKS: This species is characterized particularly by the coloration of the radioles, which have a single broad band of red around the proximal part. Mortensen (1943), in discussing the species *M. pulchellus*, *M. composus* and *M. annulatus*, gave features such as the number of coronal plates

for a given size and the size of the peristome to distinguish their tests. For example, he noted that in *M. annulatus* the peristome is smaller than the apical system. However, for the three species mentioned above, respectively only one, two and three specimens were available to him for study so that the range of variation in test characters is poorly known. The specimens from the Roe Calcarenite show wide variation in test characters and are here regarded as belonging to the one variable species. It seems likely that the living species, when better known, will exhibit similar variation. The specimens are referred to *M. annulatus* essentially on the basis of ambulacral and interambulacral structure and ornament. One specimen (SU 13320), appears to conform closely with the dimensions of the second of Mortensen's (1943, p. 172) specimens, except that the peristome is larger.

#### ACKNOWLEDGMENT

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## A REVIEW OF SOME ASPECTS OF THE GERMINATION OF ACACIAS

By A. K. CAVANAGH\*

**ABSTRACT:** The morphology and anatomy of *Acacia* seeds are considered with special attention to the role of the strophiole in overcoming hard seededness. The variables which can influence germination, both in the laboratory and in the field, are discussed. These include the role of birds and animals in seed dispersal and germination, the part played by fire, and the effects of various seed coat treatments used to enhance germination. The majority of such treatments act on the strophiole and thus render the seed permeable. Treated seeds have been found to remain viable for periods of up to three years.

In a number of areas, notably the biochemical aspects of germination, little is known about Acacias and a plea is made for more systematic studies of important species. In particular, it is highly desirable that optimum treatment conditions be established for as many species as possible to provide much-needed practical information.

### INTRODUCTION

Acacias form a large genus within the sub-family Mimosoideae of the Leguminosae family. They have a very wide distribution in tropical and sub-tropical areas of the world, notably Australia, Africa, Asia and the Americas. While the exact number of species is unknown, it is considered to exceed 1200 of which some 700 are found in Australia (Guinet & Vassal 1978). Additionally, a number of Australian species are widely used in many overseas countries, often for sand stabilisation and dune fixation e.g. South Africa (Ross 1975, Roux 1961), Cyprus (Raymond & Ward 1954), Libya (Messines 1952), Iran (Shaybany & Rouhani 1976), India (Venkataramany 1963), Argentina (Boelcke 1946) and Mediterranean France (de Ravel D'Esclapon 1962). They have adapted so well to these countries that in some areas they have become a considerable menace to the local flora (Control of Alien Vegetation Committee, c. 1960). Many products of economic importance are obtained from Acacias including timber for fuel, construction purposes and paper making, bark for tanning, gum arabic, perfume and cut flowers, while the foliage and seed pods are useful as top-feed for domestic and wild animals. In Australia, and to a lesser extent in South Africa and California, many species are grown as ornamental garden plants.

Consequently it might be expected that a good deal would be known about the germination of *Acacia* seeds. However, while extensive data exists for a few

species, a number of fundamental aspects of the germination process have been ignored, and much of the available information is widely scattered and arises from many unconnected investigations. It is quite noticeable that most of this knowledge comes from overseas studies, these being necessary to provide data for large-scale plantings and for sand reclamation schemes [e.g. see Sherry (1971) for details of *A. mearnsii*].

In Australia, little effort has been made to farm Acacias commercially so perhaps the need for wider investigation has not existed. This became evident to us during evaluation of the effectiveness of microwave energy in breaking dormancy of *Acacia longifolia* (Cavanagh & Tran 1979). We found that relatively little was known about the mechanism of action of treatments applied to hasten germination; data on natural regeneration and softening were also very sparse and sometimes contradictory. This paper considers these points and attempts to present a summary of the present state of the knowledge in the general areas of seed characteristics and germination. Suggestions are also made concerning aspects about which more information is required.

### SEED MORPHOLOGY AND ANATOMY

*Acacia* seeds are extremely variable in size, shape and weight, and even within a species marked differences can occur. Boelcke (1946) and Vassal (1963, 1971) studied the seeds of a total of 139 species

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and developed seed classifications based on such features as the type of funicle, the size and shape of the hilum and the strophiole\* (trace rapheale), the form and dimensions of the seed and some aspects of internal morphology such as the presence or absence of albumen (endosperm). Gopal and Thapliyal (1971) developed a classification key for 35 species of forestry seeds of the family Mimosoideae which was based on observations of the external morphology, colour and dimensions. Twenty-three *Acacias* were covered, and the work is of value in that it includes photographs of all seeds described.

It is possible from Vassal's 1971 data to estimate the thickness of the seed coat if other dimensions of the seed are known. Though there is some evidence that seed coat thickness can influence the response of the seed to various treatments, this point has received little attention. It might well prove a fruitful study and perhaps explain widely differing germination results between various species for similar severities of treatment. In general, the *Acacia* seed coat is considerably thicker than in many of the small seeded legumes such as alfalfa, clover etc. Table 1 gives typical thicknesses for several species determined on cross-sections of the seed. Though differences would almost certainly be observed with other batches, it is interesting to note that the seed coat of the desert species *A. aneura* is one of the thinnest. According to Murray et al (1978), the density of the coat is considerably greater than that of the embryo — for *A. longifolia* and *A. sophorae* they

found that between 33.7 and 43.1% of the seed mass was concentrated in the coat.

Vassal's data also enables the seed to be classified by shape. The influence of seed shape on response to treatment is another area in which little research appears to have been carried out. With impaction or percussion treatments, for example, the evidence from the work of Barton (1947) is inconclusive but appears to indicate that disc-shaped seeds respond more favourably than do spherical seeds.

Directly related to the problem of enhancing germination is the structure of the seed coat and the features or characteristics which are responsible for impermeability. The anatomy of the *Acacia* seed coat has received spasmodic attention over the years though only a few species have been examined in detail. General studies have been made by Boelcke (1946), Ishizaki *et al.* (1976), Maisel (1909) and Vassal (1971). These indicate that the structure is similar to that of other Leguminosae, with a cuticle and subcuticular layer, a layer of palisade or Malpighian cells and a third layer which Vassal calls a 'tegmen'. The more comprehensive work of Hoffmann and Kummerow (1962) on *A. caven* and of Robbertse (1973, 1974) on *A. grandicornuta* and several other African *Acacias* reveals further information about the palisade cells, the 'tegmen' and the region around the hilum. An additional feature of the palisade cells, the light line, is clearly shown in Fig. 1, adapted from Robbertse (1974). This optical effect is characteristic of many legume species and at one time was thought to contribute to impermeability. The 'tegmen' generally consists of a row of osteosclereid (or 'hour glass') cells underlain by mesophyll tissue. In *A. caven* (Hoffmann & Kummerow 1962) and several African species (Vassal 1975), the osteosclereid cells are absent and the palisade cells overlie the mesophyll tissue directly. It seems from the work of Vassal (1973) that the hour glass cells are variable in their distribution in the coat though their presence appears to play no part in the germination process. Likewise, while albumen (endosperm) has been found in the seeds of a number of species and has been used in seed classification schemes (Boelcke 1946, Vassal 1968, 1971), the layer is usually very thin, ranging from a trace to 0.4 mm. It does not appear to play a significant role in germination.

When treatments are applied to *Acacia* seeds to induce germination, it is usually considered that these soften or damage the seed coat and thus allow general water penetration. The detailed microscopy work of Robbertse (1973, 1974) calls this concept into question. He paid particular attention to the area around the hilum. Our Pl. 21 is a scanning electron micrograph of this region and shows the relationship of the three

\*The recent review of Rolston (1978) again raises the question of the 'correct' usage of the word strophiole. Following the work of Hamly (1932), the strophiole has generally been accepted as referring to a specific area of elongated epidermal cells in certain members of the Papilionate sub-family, though *Acacia* seeds have previously been claimed to possess a strophiole e.g. Preece (1971b), Winkworth (1973) for *A. aneura*. While it is possibly not the most appropriate term, in the absence of a suitable alternative I have used it to designate a small, raised area of the *Acacia* seed coat close to hilum but on the side opposite the micropyle (Pl. 21). It is variable in size, shape and colour (Vassal 1971) and a section through the strophiole reveals that the epidermal cells here are considerably shorter than elsewhere in the coat (Pl. 22).

Many species within the sub-families Mimosoideae and Caesalipinoideae possess this structural feature and it is unfortunate that there is no generally agreed term which can be used to describe it. In the literature, the following words have been applied: 'plage sub-hilare' (Pitot 1936), 'marca rapheale' (Boelcke 1946), 'tracé rapheale' (Vassal 1963, 1971), 'lens' (Brown & Booyesen 1969, Gopal & Thapliyal 1971) and 'rapheole' (Robbertse 1973, 1974).

It is thus highly desirable that in the future some attempt be made to standardize terminology applied to leguminous seeds.

TABLE 1  
THICKNESS OF SEED COATS OF TYPICAL *Acacia* SPECIES

SPECIES	THICKNESS $\mu\text{m}$	SPECIES	THICKNESS $\mu\text{m}$
<u>A. accola</u>	170 - 180	<u>A. mearnsii</u>	180 - 200
<u>A. aneura</u>	120 - 135	<u>A. melanoxylon</u>	190 - 200
<u>A. baileyana</u>	125 - 135	<u>A. normalis</u>	175 - 200
<u>A. botrycephala</u>	170 - 180	<u>A. pravissima</u>	150 - 170
<u>A. brachypotrya</u>	260 - 300	<u>A. pycnantha</u>	180 - 190
<u>A. buxifolia</u>	140 - 160	<u>A. saligna</u>	190
<u>A. calamifolia</u>	150 - 170	<u>A. suaveolens</u>	180
<u>A. cyclops</u>	240 - 260	<u>A. triptera</u>	105
<u>A. implexa</u>	125 - 140	<u>A. victoriae</u>	> 430
<u>A. longifolia</u>	150 - 160		

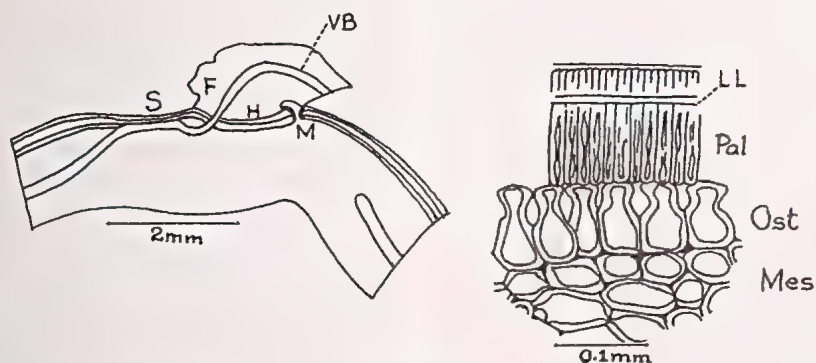


Fig. 1 — Anatomy of the seed coat of *A. grandicornuta*. (Modified from Robbertse (1974), used with permission). F = funicle; H = hilum; LL = light line; Mes = mesophyll cells; M = micropyle; Ost = osteosclereid cells; Pal = palisade or Malpighian cells; S = strophiole; VB = vascular bundle.





PLATE 21

Scanning electron micrograph of the hilum region of *A. suaveolens*. S = strophiole; H = hilum; M = micropyle.

important features, the hilum, the micropyle and the strophiole (Vassal's 'tracé rapheale', Robbertse's rapheole'). The vascular bundle enters the seed via the funicle at the hilum, penetrates deeply into the inner layers of the seed coat and then bends upwards coming close to the surface at the strophiole (Fig. 1). Newman (1934) illustrates this very clearly with his photomicrographs of *A. baileyana* while Corner (1951) confirms that in many legume seeds, the vascular bundle takes a characteristic bend around or through the 'lens' (strophiole). Under low power magnification, the strophiole appears as a small, raised area generally of the same colour as the rest of the coat, though in *A. farnesiana* and several African species, it is a distinct white spot. According to Robbertse (1974), the palisade cells of the seed coat continue across the hilum, and in the area of the strophiole they are shorter and more poorly developed (Pl. 22). This is in marked contrast to the strophiole in many other legumes where the palisade cells are much longer than elsewhere and are bowed and in a state of considerable tension (Aitkens 1939, Hagon & Ballard 1970, Hamly 1932, Zimmermann 1936). On the basis of laboratory experiments and from field observations Robbertse concluded that the strophiole was the area of the seed coat most likely to suffer damage in the soil, or to be attacked by micro-organisms, and that it was probably responsible for overcoming hard seededness in Acacias. Subsequent work has shown that 'pricking'

the strophiole with a scalpel or needle allows rapid germination of *Acacia* seed (V. N. Tran, pers. comm.)

The nature of the seed coat impermeability in Acacias appears to have been little investigated. By excising the seed coats, Kao (1971) and Kaul and Manohar (1966) have shown that dormancy is associated only with the seed coat and not the embryo. For the species examined, *A. confusa* and *A. senegal* respectively, rapid and nearly complete germination followed immersion in water. Kao further claimed that he detected no inhibitor in the seed coat; additionally, his results appear to indicate that the seed coat functions as a barrier to oxygen diffusion. Though secondary or embryo dormancy has been invoked as an explanation of decreased germination rates following storage (Aveyard 1968) or after nicking as compared with boiling water treatment (Clemens *et al.* 1977), there appears to be no experimental proof of this.

Rees (1911) and White (1908) considered the cuticle was responsible for impermeability in small seeded legumes, while in larger seeds, where the cuticle tended to be relatively thin, they thought that part of the palisade contributed to restriction of water entry. Ballard (1973) subsequently showed that the waxy cuticle in legumes was water permeable. With *Trifolium subterranean* L.C.V. Geraldton he found the palisade cells to be impermeable, or only slowly permeable, to a considerable depth below the light line. The detailed anatomical studies of Hamly (1932)

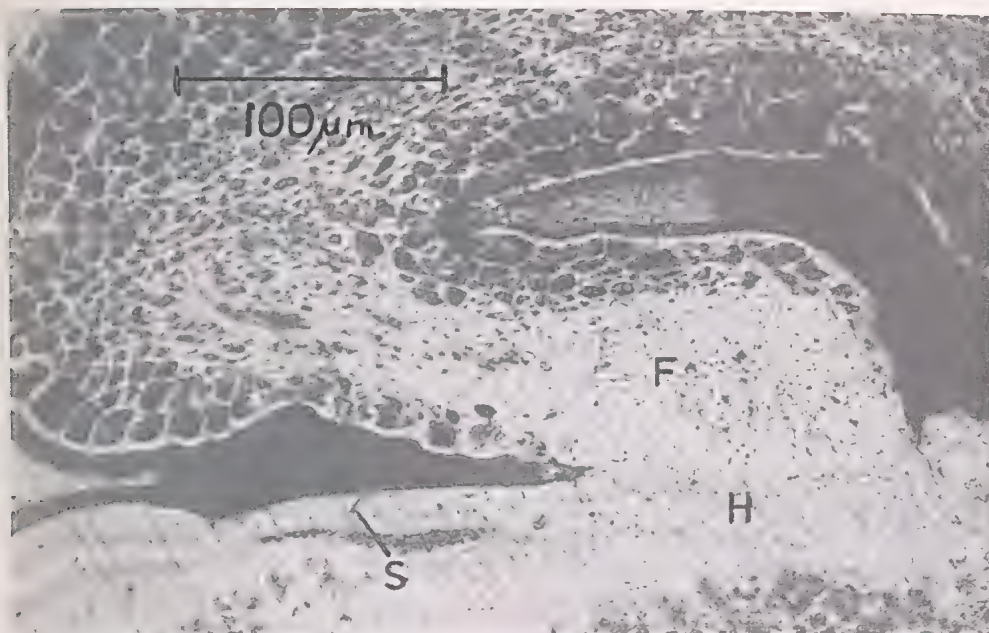


PLATE 22

Longitudinal section through the hilum and strophiole of *A. suaveolens*. F = funicle;  
H = hilum; S = strophiole.

Length of Malpighian  
Cells:  
Distance to light line:

Normal Coat At Strophiole	
70 $\mu\text{m}$	40 $\mu\text{m}$
45 $\mu\text{m}$	20-22 $\mu\text{m}$

on *Melilotus alba* established that the suberin matrix in which the caps of the palisade cells were embedded was responsible for impermeability. No similar studies exist for Acacias though several lines of evidence indicate that the situation here may be somewhat different.

Firstly, a number of species are known to germinate freely without the need for pretreatment, e.g. many dehiscent African species (Lamprey *et al.* 1974), *A. argyrodendron* (Pedley 1978), *A. cambagei* (Hall *et al.* 1975 a), *A. harpophylla* (Coaldrake 1971, Hall *et al.* 1975 b, Johnson 1964), *A. peuce* (Hall *et al.* 1975 c)

Secondly, it has been established that some species contain a high proportion of soft seeds if picked 'green' i.e. before the pods have dried. These include *A. mollissima* (now *A. mearnsii*) (Isikawa 1960), *A. senegal* (Kaul & Manohar 1966) and *A. aneura* (Everist 1949). However most of the above seeds will develop impermeability when stored and it is suggested that at least for *A. senegal*, this is associated with progressive suberisation of the testa as the seed matures (Kaul & Manohar 1966). This is partially confirmed by the work of Isikawa (1964) who collected green seeds with a moisture content of 62% and dried them slowly in the shade and rapidly in light. Impermeability developed at 10-12% moisture, irres-

pective of drying rate, and reached a maximum at about 6% moisture, a level found by Quinlivan (1971) to confer full impermeability in other legumes.

It is evident that more information is required on the nature of seed coat impermeability in Acacias, especially the mechanism of its development in storage. Additionally, it would be very useful to know whether all species contain a high proportion of soft seed if picked green and if low temperature is the only storage requirement to maintain the seeds in this state.

## CONDITIONS AFFECTING GERMINATION AND GROWTH:

### NATURAL REGENERATION

The ability of a species to replace itself is of major ecological and economic importance. Despite this, surprisingly few species have been studied in detail. (See Everist 1949, Preece 1971a and Symposium, *The Mulga Lands of Australia* 1973 for *A. aneura*, Wickens 1969 for *A. albida*, Coaldrake 1971 and Johnson 1964 for *A. harpophylla* and Cheema & Qadir 1973, Oheid & Seif el Din 1970, 1971 and Seif el Din & Oheid 1971a, 1971b for *A. senegal*.) Most of our current understanding of natural regeneration comes from scattered and often unconnected field ob-



servations. This has sometimes led to confusion as to the status of particular species e.g. the valuable fodder reserve, *A. aneura* has been reported to be dying out in areas of Australia (Beadle 1948, Jessup 1951, Lange 1966) and the reasons for this are far from clear. More recent observations, however, suggest that heavy grazing by domestic animals and rabbits might be responsible. In their absence, good regeneration has been noted (Woods and Forests Department, South Australia, pers. comm.). Similar conclusions have been reached by Burroughs (1973). Other species seemingly do not have the ability to withstand competition. In the Sudan, Seif el Din and Oheid (1971a) noted that *Acacia senegal* forests if left undisturbed degenerated into open woodlands, and seedling replacement was insufficient to maintain species dominance. As opposed to this, some species are very aggressive colonisers of new ground and show remarkable persistence even in very adverse conditions. Notable among these are *A. cyclops* and *A. saligna* (Roux & Middlemiss 1963), *A. farnesiana* (Scifres 1974), *A. harpophylla* (Johnson 1964) and *A. melanoxylon* (Farrell & Ashton 1978, Pedley 1978). In some but not all the above cases, vegetative reproduction, usually from damaged roots, can greatly aid the plant's ability to resist attempts to remove or destroy it.

Very little is known of the regeneration processes operating in Acacias in the field. In many species, the situation is complicated by apparent sporadic flowering and seed set, so that with short term observations it is difficult, if not impossible, to determine with certainty which climatic factors influence regeneration. The studies of Davies (1976) are important here. Over the period 1960-1971, he observed a minimum of five individual trees on up to four sites in an arid area of Western Australia. Twenty-four species, twelve of them Acacias, were involved and Davies found that flowering and fruiting were with one exception, seasonal. Fruiting was found to depend on rain falling under particular temperature and/or photoperiod conditions e.g. *A. aneura* fruits after summer rain while for *A. cuthbertsonii*, winter rain is required. Davies concluded that at least for the test area, arid zone shrubs show a remarkably regular calendar of flowering and fruit production.

Some characteristics which appear to be important in regeneration have been discussed from time to time. These include: a combination of suitable temperature and rainfall, disturbance of soil, clearance of forest (which increases light intensity and eliminates competitors), the presence of a moderate layer of mulch and, most importantly in Australia and South Africa, the presence or absence of regular fires. Grazing by animals, insect attack and/or predation of seeds and destruction of seedlings are factors which are

claimed to mitigate against successful regeneration.

Particularly in desert areas, a number of species appear to have developed special adaption to the harsh conditions. These include an ability to germinate and establish rapidly, often within 3-5 days of rain (Johnson 1964, Halevy 1974), an ability to survive in high soil temperatures and still form rhizobium nodules (Habish 1970), high tolerance to extreme moisture stress (Burroughs 1973), metabolic processes which are active under a wider range of environmental conditions than are those of most temperate zone species (Hellmuth 1971), and a feature noted in *A. senegal*, and which may exist in other Acacias, of producing two types of seeds, one of which germinates quickly and the other only after an extended period. This characteristic is found not only in seeds from the same tree but also in seeds from individual seed pods. On being wetted, about half will germinate within 48 hours, while the rest will remain unaffected for up to 15 days. This is considered to be a natural provision against total failure if early rains are not followed up (Forests Department of the Sudan 1960).

#### THE ROLE OF FIRE

Fire plays a major role in controlling the Australian (Gill 1975) and South African (Roux & Middlemiss 1963) flora. Acacias often tend to become dominant species after fire and it is usually assumed that the heat of the fire softens or cracks the seed coat, thus permitting germination if suitable rains fall. Several investigations have been made of the effect of fire on germination of soil-stored seed (Beadle 1940, Floyd 1966, 1976, Omer 1975, Shea *et al.* 1979) while Martin and co-workers (1966, 1975) have discussed the effects of moist and dry heat on the germination of forest legumes.

The intensity and duration of the fire will control the temperature reached at the surface and at various depths below the surface, and hence will have an important influence on softening of hard seed. Soil temperatures in a number of typical fire types have been measured (Ahlgren & Ahlgren 1960, Beadle 1940, Cromer & Vines 1966, Floyd 1966, Humphries & Lambert 1965, Roberts 1965, Vines 1968); some of this data is summarized in Table 2. The temperatures vary widely, depending on such factors as the soil moisture and soil type, wind and ambient temperature, amount of fuel available and the development of an (insulating) ash bed.

While *Acacia* seeds can withstand prolonged periods of exposure to dry heat, they are more adversely affected by moist heat (Beadle 1940) and most species are killed by temperatures of 110-120°C for short periods. In very fierce burns such as occur in bulldozed windrows, most seeds to a depth of 100 mm

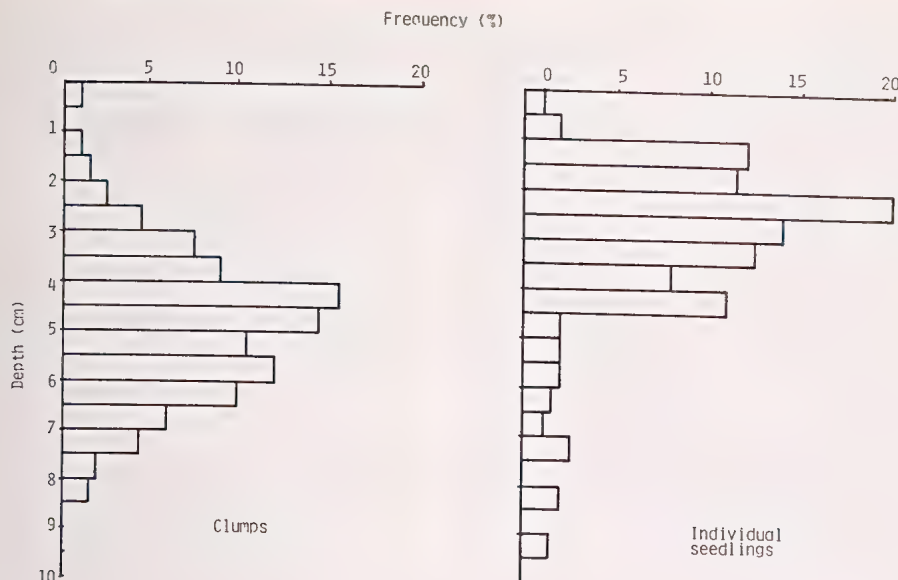


Fig. 2—Depths of emergence of *A. pulchella* seedlings following an intense fire [From Shea *et al* (1979) used with permission]

or more would be destroyed. On the other hand, in light bush and scrub fires, and in controlled burns, only surface seeds would be affected. Vines (1968) has found that soil temperatures even in moderately intense controlled burns often only reach 40°C at a depth of 25 mm. Even though *Acacia* seeds have been shown to be present down to considerable depths in virgin bushland (Ewart 1908), this apparently is not always the case. Soil samples taken from beneath coastal *A. sophorae* scrub in South Australia revealed that almost no *Acacia* seeds were present in the top 50 mm despite evidence of numerous recently opened pods (Barbour and Lange 1967). Studies with *A. senegal* in the Sudan revealed that up to 84% of surface sown seed was destroyed or removed by insects, millipedes and rodents (Seif el Din & Oheid 1971a). In Western Australia, Shea *et al.* (1979) found that ants frequently buried seeds of *A. pulchella* and other legumes so that two months after seed fall, almost no seeds were seen on the surface. Thus, burial of seeds by ants and other creatures can be a means of ensuring their survival in fire. It has been demonstrated that seedlings of at least some *Acacia* species can emerge from depths of 60 to 90 mm (Scifres 1974, Shea *et al.* 1979). Hence a substantial germination can still be achieved even after a very intense fire, and disturbance of burnt ground can enhance this. However, while many writers have emphasized the role of fire in regeneration of legume species, it appears that it is not a pre-requisite for field germination. Boomsma (1969) and Preece (1971a) have noted widespread regrowth of *A. aneura* in areas not recently subject to fires and, for this species at

least, other factors such as suitable rainfall and/or high ambient or soil temperatures may also be important.

#### NATURAL SOFTENING AND SEED VIABILITY

In the absence of knowledge to the contrary, it is usually assumed that hard seeds are rendered permeable while lying on the ground through action on the seed coat of fungi, bacteria and possibly soil acids. Softening is thus thought of as being unlocalised in its effect. However, work by Quinlivan (1961, 1966) with several Papilionate legumes and Robbertse (1974) with *A. robusta* indicates this may not always be the case. Quinlivan (1961, 1966) found that long term diurnal temperature fluctuations caused fracture of the strophiole and he was able to correlate laboratory results with field data and establish that seeds softened naturally become permeable substantially only at the strophiole and not elsewhere.

Using similar techniques, Preece (1971b) was not able to increase germination of *A. aneura* even after 12 months, though it is probable that his maximum temperature of 45°C was too low in relation to summer soil temperatures in many areas of Central Australia. Robbertse (1974) collected seeds from the ground under trees of *A. robusta* and after visual examination, found that a high proportion had suffered damage to the rapheole. As laboratory experiments gave germination results in excess of 80% for this seed, Robbertse believed that (damage to) the rapheole might be responsible for overcoming hard seededness in *Acacia* seed.

Directly related to softening is the question of



TABLE 2  
SOIL TEMPERATURES REACHED IN VARIOUS FIRE TYPES

FIRE TYPE/SOIL	MAX. TEMP. AT DEPTHS INDICATED BELOW SURFACE (mm)/°C					TIME TO REACH MAX. TEMP.(MINS.)	DURATION OF HEATING	REFERENCE
	0	25	50	100	200			
Log pile (4.25x2.4x1.8m) Soil-dry sandy, 3% moisture	742	605	393	205	100	250 350 390 ≈660 - 700 510	1600 mins > 100°C " 1570 mins > 100°C 1420 mins > 100°C 1200 mins > 100°C	Roberts (1965)
Bulldozed windrow (200x6x2m) Soil - sandy 12% moisture	-	330	≈125	95	70	- 360 570 420 660	- 960 mins > 100°C ≈520 mins > 100°C ≈900 mins > 95°C ≈1150 mins > 50°C	Cromer and Vines (1966)
Slash Fires Soil - clay loam "dry" (1) Light burn  (2) Heavy burn (*Thick ash bed developed)	500   360*	45   80	42   80	30   75	30   ≈50	- - - - 130 300 440 450 550	- - - - ≈1000 mins > 100°C ≈350 mins > 75°C >1000 mins > 50°C >800 mins > 50°C >500 mins, 40-50°C	Humphries and Lambert (1965)

seed viability, both in soil and under laboratory storage conditions. Field observations by Althofer (1974) for *A. homalophylla*, Moffatt (1952) for *A. mearnsii* and Farrell and Ashton (1978) for *A. melanoxydon* confirm that *Acacia* seeds can remain viable and unsoftened in soil for at least 50 years, and provide evidence of the very great stability of the seed coat even under adverse conditions. The extensive studies of Ewart (1908) indicate that seeds of some species can remain viable in laboratory storage for at least 68 years. However, no systematic study has been made of the decline in viability with age of *Acacias*. Aveyard (1968) noted a definite reduction in ability to germinate over a twelve month period. He believed that with older seed, seed coat impermeability was no longer the dominant factor and a more complex breaking of dormancy, probably involving the embryo, was required, e.g. chemical action or moist heat. If such an ageing effect

exists, and it should be noted that Shaybany and Rouhani (1976) were unable to substantiate it for *A. cyanophylla* (syn. *A. saligna*), then it may in part explain the widely varying germination results reported in the literature for the same species when given nominally the same severity of seed coat treatment.

More data is required on both long-term viability of seed and the mechanism(s) of natural softening. This information would be valuable in understanding the widespread distribution of *Acacias* and their ability to colonise new areas given favourable conditions.

#### VARIABLES INFLUENCING GERMINATION BEHAVIOUR

There are only scattered references to the effects of such features as date of collection of seed before pod dehiscence, seed size and weight, seed moisture, position of seed in pod, age of seed, soil moisture and soil temperature during germination and

seedling growth, and depth of sowing on the germination and subsequent growth of Acacias, and it is unfortunate that more systematic studies have not been made. Isikawa (1960) and Kaul and Manohar (1966) advocated collection approximately 10-14 days after the appearance of green pods filled with seed i.e. when the pods were beginning to turn brown. This seed, at least in species examined, *A. mollissima* (syn. *A. mearnsii*) and *A. senegal* respectively, was up to 90% soft when sown within several months of harvest, but with prolonged storage at room temperature the percentage of hard seeds increased. Storage at 5°C maintained the original percentage germination for at least a year (Isikawa 1960).

Similar data has been obtained by Coaldrake (1971) with *A. harpophylla* where the development of hard seededness was dependent on the area of collection (and hence rainfall and soil conditions), taking between 12 and 90 weeks at room temperature; however, seeds held at -20°C retained viability and remained soft for up to five years.

In areas where insect infestation is severe, it is sometimes advisable to collect green seed and sow it in the hope of arresting the attack before too much of the seed is destroyed. Karschon (1975) found with *A. raddiana* in Israel that very green and immature seed of 156% moisture content gave up to 46% germination. However, seed coat dormancy was induced by storage for 12 days at room temperature or by 24 hours at 65°C. All the above work suggests that if seed is collected at a suitable time, it may germinate without pre-treatment. However, no systematic studies have been made concerning the possibility of an after-ripening period being present in Acacias; Drees (1941) claimed that up to four months was required in four out of eleven species he germinated.

In a number of other species, seed size is known to influence germination or growth behaviour. No similar information exists for Acacias though there is some evidence that the size of the seed can affect germination (Isikawa 1959) and sensitivity of the seed coat to treatment (Moffatt 1952). Moffatt considered that both seed coat hardness and seed size were governed by genetic factors and pointed out that individual trees of *A. mearnsii* will sometimes show significant differences in seed size, a fact already established for *A. decurrens* by Philp and Sherry (1946). Larger seeds either had more sensitive seed coats (i.e. required less drastic treatments for germination) (Moffatt 1952) or remained soft after picking for considerably longer than did smaller seeds (Isikawa 1959). In the latter case, the seed size was related to position of the seeds in the pod, with the larger seeds occurring in the middle portion. The smaller seeds in the top of the pod were predominantly hard, even immediately after harvest,

while in the lower section, the hard proportion was intermediate. What is not known is whether large and small seeds from the same population, or even from adjacent trees, will respond differently to similar treatments. With *A. melanoxyton*, Farrell and Ashton (1978) found no correlation between germination percentage and seed weight with seeds from different localities and rainfalls. Similarly, no specific observations were made by Coaldrake (1971) with *A. harpophylla*, even though seed weights of his samples varied from 1.5 to 24.45gm/100 seeds, again dependent on the area of collection. The effects of soil moisture on germination and seedling growth have been studied by Burrows (1973), Habish (1970), Kaul and Manohar (1966), Pathak *et al.* (1976), Scifres (1974), Watanabe (1959). With *A. mollissima* (syn. *A. mearnsii*) Watanabe (1959) found that germination percent was not adversely affected until the soil moisture fell to 20% (8.4 atmospheres soil moisture tension). By permanent wilting point, 14.5% moisture (15 atmospheres), the percent germination had dropped to less than half. Kaul and Manohar (1966) state that soil bed moisture should not be allowed to drop below 600 joules/kg (= 6 atmospheres) for satisfactory germination of *A. senegal*. In comprehensive experiments with *A. farnesiana*, Scifres (1974) showed that a range of moisture tensions from 0 to 16 atmospheres had little effect on germination at the optimum temperature of 30°C, though seedling growth was adversely affected at the higher moisture tensions.

The influence of soil moisture on seedling growth seems to be governed to a large extent by the origin of the parent plant. Five desert species from the Sudan were able to grow and form nitrogen (rhizobium) nodules at soil moistures as low as 7.5%, though optimum growth occurred at 15% (Habish 1970), which is approximately the permanent wilting point of *A. mearnsii*, a tree from non-arid areas. Watanabe (1959) showed for this species that as soil moisture fell below 30%, the transpiration rate of the plant decreased, though the water content of the leaves did not change significantly until the permanent wilting point was reached. Another arid zone species from Australia, *A. aneura* is especially drought resistant and seedlings can survive at a moisture stress of approximately 500 atmospheres (Burroughs 1973).

High soil temperatures in the field are known to inhibit germination and seedling establishment and similar information has been obtained for several species from laboratory germination trials where fixed temperatures in excess of 30°C have been used (Scifres 1974, Shaybany & Rouhani 1976). *Acacia aneura*, however, again demonstrates the ability of arid zone species to tolerate a wide range of environmental conditions: it is capable of successful germination between



10°C and 35°C (Burroughs 1973). With Sudan Acacias, Habish (1970) established that seedlings were able to grow and produce effective nitrogen nodules at temperatures as high as 35°C; this may be related to the resistance of rhizobium strains of Acacias to high temperatures (Habish & Khairi 1971) and explain their ability to colonise hot and dry areas. In general, Acacias appear to favour coarse textured soils with a pH close to neutral, and germination studies (Scifres 1974) and growth trials (Habish 1970) show that seedling development is retarded by major deviations from neutrality. Subsequent growth in the field may be affected by either inability to form nodules in highly acid soils or by a general decline in both growth and nodulation in alkaline soils.

Almost no attention appears to have been given to the determination of optimum sowing depth for germination. Such information is of value for large scale seed sowing programmes and is also of importance in understanding the natural regeneration of buried seeds. Scifres (1974) determined that the optimum planting depth for *A. farnesiana* was 20 mm, though seedlings could emerge from as deep as 60 mm; however, here the percentage germination was lower and seedlings were much smaller and weaker. Work at the Wattle Research Institute in South Africa showed that *A. mearnsii* could be planted up to 100 mm deep and still yield a 66% survival after eight weeks. Deep sowing is claimed to have some advantage in areas where the soil dries out rapidly or where little post-sowing watering is available (Sherry 1971). By excavating seedlings which established after fire, Floyd (1966, 1976) and Shea *et al.* (1979) demonstrated that many species could emerge from up to 50 mm, while a maximum of 90 mm was measured for *A. pulchella* (Fig. 2). Scifres (1974), Brown and Booyesen (1968) and Cheema and Qadir (1973) have all shown that germination and establishment from surface sown seeds, particularly under field conditions, is very poor, the seed must be covered with 10-20 mm of soil, probably to give adequate anchorage to the seedling root and prevent desiccation by the cotyledons.

#### THE ROLE OF ANIMALS AND BIRDS

The part played by animals and birds in the dispersion, distribution and germination of seeds has been the subject of a number of studies: Gwynne (1969), Halevy (1974), Janzen (1969, 1971), Jarman (1976), Krefting and Roe (1949), Lamprey (1963, 1967), Lamprey *et al.* (1974), Middlemiss (1963). The earliest investigations of *Acacia* seed ingestion appear to be those reported by Troup (1921) covering experiments carried out in the Sind area of India in 1911-1912. Pods of *A. arabica* (syn. *A. nilotica*) were fed to penned sheep and goats. The seed was regurgitated by

the animals and in subsequent trials was found to have an enhancement in germination of up to 35%. Troup remarks that such practice is common in India to obtain treated seeds for nursery sowings.

There is little direct knowledge on the role of animals in seed dispersal in Australia. Among the trees used to provide sheep and cattle fodder, *A. argyrodendron* and *A. oswaldii* are noted as often producing heavy crops of pods which are readily eaten (Hall 1972), while Everist (1949) states that the pods of *A. aneura* are much sought after by sheep; it is possible they are somewhat more palatable than the leaves which are normally eaten. Unpublished reports of the Queensland Department of Agriculture (cited by Pedley 1978) also make reference to cattle and goats as eating the pods and dispersing the seed of the naturalised African species *A. nilotica*. This confirms observations concerning this species made in India and in Africa as discussed below.

Much of our current knowledge of the part played by animals in dispersing seed and enhancing germination comes from the work of Lamprey and co-workers at the Serengeti Research Institute in Tanzania. Lamprey (1963, 1967) found *Acacia* seedlings growing in droppings of impalas, elephants, dik-diks, and gazelles, and in goat dung in abandoned goat enclosures. He also noted that mountain goats, domestic goats and camels, all readily ate *Acacia* pods. Gwynne (1969) showed that in dry periods, up to 65% on a dry weight basis of the food intake of domestic cattle was of *Acacia* pods and seeds.

In the particular case of the African Acacias, two interesting lines of information emerged from these studies. Firstly, it was found that species with non-dehiscent pods were particularly attractive to large herbivores though they had no special nutritional advantage over other species with dehiscent pods (Gwynne 1969). Table 3 gives average analyses of seeds and pods of various African species compared with leaf analyses for a number of Australian species which are used as fodder for sheep and cattle (Everist 1969). The analyses show a remarkable similarity but as Everist states, they tell us nothing about the reason the materials are eaten by animals. Palatability and conspicuousness appear to weigh heavily in favour of the pods as compared with leaves and shoots; the non-dehiscent African species in particular have large, fleshy pods and are readily eaten either on the tree or within a few hours of falling to the ground. Additionally, their seeds are hard and rounded and seemingly ideally suited to easy passage through the animal's digestive tract. Secondly, in both Africa (Lamprey *et al.* 1974) and in Israel (Halevey 1974) a relationship was found to exist between Acacias, bruchid seed beetles and herbivores. The bruchid larvae hatches on

the surface and penetrates the seed while it is still green. As the beetle grows it feeds within the seed which in the meantime has ripened so that the insect is protected by the hard seed coat. The adults emerge by cutting a hole through the coat, in much the same manner as does the chalcid wasp which infests *A. aneura* (Preece 1971b). Infestation as high as 99% was found in some species in Israel. However, even for severely attacked seed lots, Halevy (1974) showed that germination after passage through the digestive tract of gazelles was usually enhanced over control batches. He considered that seed would still be viable if the embryo axis was not damaged by the beetle; in this case, the penetration of fluids, e.g. gastric juices, would result in an increase in germination and an improved germination rate, the latter regarded as im-

portant in desert survival. Similar trends were found in Africa (Lamprey *et al.* 1974) though in this area, the level of detrimental seed infestation was somewhat lower.

The mechanism of action on the seed coat during passage through the digestive tract is not known. It is usually considered that the coat is 'softened' in some way, perhaps by gastric juices, or may suffer damage in the animal's mouth during mastication or regurgitation. The waxy, water-repellent seed coat of Acacias is remarkably resistant even to strong reagents such as concentrated sulphuric acid so it is unlikely that stomach acids will have much effect. With larger animals such as elephants (Lamprey *et al.* 1974) and domestic cattle (Gwynne 1969), apparently little of the seed is damaged and this is reflected in the relatively

TABLE 3  
ANALYSIS OF PODS, SEEDS AND LEAVES OF VARIOUS *Acacia* SPECIES (Moisture Free %)

SPECIES	PORTION	CRUDE PROTEIN	CRUDE FAT	CRUDE FIBRE	N.F.E.**	ASH	REFERENCE
<i>A.albida</i> *	P + S	13.48	1.59	37.26	43.26	4.41	Gwynne (1969)
	S	26.59	2.69	6.92	58.94	4.86	
	P	7.81	1.38	32.84	52.46	5.51	
<i>A.albida</i> *	P + S	10.03	1.76	25.21	58.84	4.16	
	S	28.36	2.55	6.6	58.71	3.78	
	P	7.42	0.84	32.84	54.75	4.15	
<i>A.nilotica</i> <i>subsp subulata</i> *	P + S	12.44	4.76	31.87	46.65	4.28	
	S	20.04	9.65	32.50	33.09	3.92	
	P	6.84	1.81	23.19	63.23	4.93	
<i>A.sieberana</i> *	P + S	11.73	-	39.82	42.81	4.84	
	S	18.95	3.56	20.51	53.33	3.65	
	P	6.84	1.81	23.19	63.23	4.93	
<i>A.hockii</i> <sup>+</sup>	P + S	16.53	2.23	27.52	48.04	5.68	
	S	25.92	4.16	32.32	31.68	5.92	
	P	8.96	1.15	45.50	40.33	4.06	
<i>A.aneura</i> <sup>++</sup>	L	11.7	2.7	20.0	49.6	6.9	Everist (1969)
<i>A.pendula</i> <sup>++</sup>	L	13.2	3.4	29.6	46.2	7.8	
<i>A.cana</i> <sup>++</sup>	L	11.3	3.2	30.2	48.6	6.8	
<i>A.cambagei</i>	L	13.3	3.1	15.9	55.2	11.0	
<i>A.harpophylla</i>	L	13.6	2.2	25.8	53.0	5.3	
<i>A.deanei</i>	L	14.3	4.8	18.9	55.6	3.4	

\* Indehiscent Pods

+ Dehiscent Pods

\*\* Nitrogen Free Extract

++ Most useful as fodder

P = Pods

L = Leaves

S = Seeds



low percentage germination enhancements observed, typically less than 40%. On the other hand, gazelles (Halevy 1974) and impalas (Jarman 1976) destroy most of the seed consumed and often less than 5% is passed whole. It is highly probable that most of this has also suffered some damage.

While birds are often credited with widespread dispersal of seed, there is little positive evidence to support this. Examination of stomach and crop contents (Frith & Barker 1975, Frith *et al.* 1974, 1976, Lea & Gray 1935) and observations of eating habits (Davies 1976, Middlemiss 1963, Pedley 1978, Preece 1971b) reveal that emus, doves, pigeons, cockatoos, galahs, parrots and perhaps lorikeets are the main species likely to eat *Acacia* seeds. In some cases, if the seed is passed whole and the birds are wide-ranging, they are likely to be highly efficient agents of dispersal. With parrots, galahs, cockatoos and pigeons, a high proportion of the seed is probably damaged or destroyed, if not during feeding then by grinding in the bird's gizzard. It is not often realized that this grinding action can be very severe though Schorger (cited by Janzen 1971) found that Peccan nuts with a crushing strength of 333.6 N were completely ground up by turkeys within an hour. It would be interesting to learn of the fate of *Acacia* seeds during passage through turkeys as Johnson (1964) suggests that the Australian turkey (*Bustard-Eupodotis australis*) might be responsible for distributing seed.

The results of Krefting and Roe (1949) are also of interest here. Though they did not test *Acacia* seed, of the other 16 species fed to birds, eight were shown to have marked improvement in germination after passage through the birds intestines. Weight losses of up to 20% were recorded as compared with controls, and the authors attributed this to seed coat thinning.

Some species of *Acacia* appear to be ecologically adapted to dispersal by birds and ants. The size, shape and colour of the funicle may attract birds e.g. the bright orange, encircling funicle of *A. cyclops* (Middlemiss 1963). Red or orange arils (Pedley 1978) or seeds enclosed in pulp such as occurs in some Central American species (Janzen 1969) are also examples of specialized development. Berg (1975) estimates that up to 300 Australian *Acacia* species are distributed by ants. They apparently possess well-developed 'elaiosomes' (ant attracting structures). The ants remove the elaiosome and discard the seed, often by burial under rocks or in the soil. The distance over which large seeds can be moved by this means is not great but Shea *et al.* (1979) observed one ant species transport a total of 46 seeds a distance of 1.9 m in one hour. The main effect of ants is to re-distribute seeds in the soil; such burial can often ensure their survival in fires.

## TECHNIQUES FOR ENHANCING THE RATE OF GERMINATION:

### LABORATORY GERMINATION STUDIES

The International Seed Testing Association (1966) lists the following recommendations for germination studies of *Acacias*: germinate on top of filter papers in petri dishes either at constant temperature of 20°C, or alternating temperatures between 20° and 30°C, the cycle being 16 hours at the lower temperature and 8 hours at the higher, with up to three hours changeover period. Germination should be done under light for at least 8 hours in each 24 hours; with alternating temperature cycles, the illumination period is during the high temperature section of the test. The prescribed duration of the test is approximately 28 days with maximum permissible of 35 days; the first count is made between six and 8 days.

Because of the practical difficulties with some aspects of the above procedures, most germination studies have been carried out at constant temperatures or in the fluctuating temperatures of greenhouses. For temperate zone species, fixed temperatures between 23 and 27°C have been found satisfactory. Arid zone and tropical species usually require a higher temperature and the range of 27 to 32°C has been employed. *Acacias* are not usually regarded as light sensitive and germination studies have been made in complete darkness and under continuous illumination. Preece (1971b) and Scifres (1974) have shown that for *A. aneura* and *A. farnesiana* respectively, germination results were identical whether darkness or light was used. Both nursery soil and sand have been used as germination media and in both it appears that the duration of the test should be extended to perhaps 45 or even 60 days. To minimise fungal attack, seeds are often dipped in a fungicide solution prior to test or even germinated in a weak solution of the fungicide. The criteria of germination is usually taken as extension of the radicle 1-3 mm beyond the testa or as emergence of the cotyledons above the soil.

### SEED COAT TREATMENTS

The water impermeable seed coat has already been established as the major reason for dormancy in *Acacia* seeds. Numerous techniques have been developed aimed at rendering the coat permeable but essentially they all fall into one of two major classes. (a) 'Dry' treatments: heat, impaction or percussion, temperature fluctuations, microwave energy, nicking or chipping, and machine scarification. (b) 'Wet' treatments: boiling or hot water, acids, organic solvents, oxidising agents such as hydrogen peroxide and alcohols, freezing, and the use of gases such as carbon dioxide.

Of these, boiling water treatment is by far the

most common, and for small quantities of seed is probably the most convenient. However, on occasions boiling water has been found to have detrimental effects on germination (Clemens *et al.* 1977, Larsen 1964), probably through its effect on the embryo. It should be noted that for most species, the time at 100°C should be as short as possible, preferably less than five seconds. Table 4 lists species which do not require boiling water, together with details of recommended treatments. The list is by no means complete and more data are required on the effect of lower temperatures and longer times to provide much needed practical information. It is evident from the results of Clemens *et al.* (1977) and Aveyard (1968) that no one type of treatment has a universally high level of effectiveness and each species responds in a different manner to a given treatment. Some of the techniques noted above, however, appear to have had little effect, at least on the species tested, and are probably not worth pursuing. These include the use of the following chemicals: hydrogen peroxide (Aveyard 1968), organic solvents except for methyl alcohol, ethyl alcohol and acetone (Brown & Booyesen 1969), freezing in ice (Brown & Booyesen 1969) and liquid nitrogen (Al-Saadawi &

Abdul-Wahab 1977), and exposure to CO<sub>2</sub> and diurnal temperature fluctuations (Preece 1971b). Several other techniques have been little used, though for a number of species they proved quite effective. Among these are impaction (Barton 1947), dry heat (Aveyard 1968, Jones 1963), microwave heating (Cavanagh & Tran 1979, Nelson *et al.* 1978, Tran & Cavanagh 1979), and machine scarification (Aveyard 1968, McIntyre 1972). However, other studies show that machine scarification can cause extensive seedling damage (Watanabe 1954). There is little doubt that except on rare occasions any process which physically damages the seed coat e.g. manual chipping, can allow nearly 100% germination of viable seed, provided that the seeds do not rot. Chipping also increases the germination rate and in some cases reduces the total time required to less than half that of seeds given optimum hot water treatment (Clemens *et al.* 1977).

#### INFLUENCE OF TREATMENT ON PERMEABILITY

Surprisingly few studies have been undertaken to determine the areas made permeable by various seed coat treatments (see Brown & Booyesen 1969, Cavanagh & Tran 1979, Robbertse 1974, Tran & Cavanagh

TABLE 4  
SPECIES ADVERSELY AFFECTED BY BOILING WATER AND/OR LONG TERM HEATING

SPECIES	RECOMMENDED TREATMENT	REFERENCE
<u>A.acuminata</u>	5 secs. max. at 100°C	Harding (1940)
<u>A.argyrodendron</u>	None if fresh	Pedley (1978)
<u>A.cabbageii</u>	None if fresh	Hall et al (1975a)
<u>A.harpophylla</u>	None if fresh	Hall et al (1975b)
<u>A.lineata</u>	?	Larsen (1964)
<u>A.peuce</u>	None if fresh	Hall et al (1975c)
<u>A.pycnantha</u>	5 secs. max. at 100°C	Harding (1940)
<u>A.senegal</u>	(None if fresh: For. Dept. Sudan 1960)	Larsen (1964)
<u>A.suaveolens</u>	200 - 600 secs at 80°C	Clemens et al (1977)
<u>A.sylvestris</u>	Short periods at up to 85°C	Floyd (1966)
<u>A.terminalis</u>	30 secs max. at 100°C, or 100 - 600 secs at 80°C	Clemens et al (1977)



1979). It is usually assumed that hot or boiling water softens the seed coat while fire or dry heat cracks it, thus allowing water entry at random sites on the surface. The superficial observations of Rees (1911) and White (1908) that the cuticle is removed by sulphuric acid has led to the mistaken belief that this layer is responsible for impermeability. More recently, Al-Saadawi and Abdul-Wahab (1977) claimed that boiling water caused destruction of part of the testa and facilitated water entry; however, this evidence is not conclusive as the actual depth of attack was not measured. In other legumes, impermeability extends to well below the light line (Ballard 1973). If a similar situation exists with Acacias, then perhaps as much as 60-80  $\mu\text{m}$  must be removed if general water penetration is to occur. Observations of treated seeds (A. Cavanagh unpublished research) show that long term boiling and sulphuric acid remove the cuticle and sometimes part of the palisade cells (see also Li, 1974, for sulphuric acid) while dry heat and microwave energy cause cracks which rarely extend beyond the light line. In order to determine actual sites of water entry, a more positive test is required over and above simple observation of the seed coat.

Brown and Booysen (1969) soaked treated seeds in osmic acid. This material (chemically osmium tetroxide) is readily reduced to black, amorphous osmium in the presence of active oxygen acceptors such as unsaturated carbon compounds, but is not affected by saturated fats (Hamly 1932). At openings or permeable areas, the unsaturated compounds present in the

palisade layer rapidly reduce the osmic acid and leave a dark stain on the surface. Brown and Booysen allowed the seeds to imbibe the solution for a short time and confirmed their surface observations by preparing sections through suspect areas. Their results are included in Table 5 and the evidence points strongly to the strophiole (lens) as being the predominant site of water entry, though some severe treatments lead to unlocalised attack and random penetration.

These original observations were confirmed independently by Robbertse (1974) following examination of seed that had become soft by long term exposure on the ground and by Cavanagh and Tran (1979) and Tran and Cavanagh (1979) who had noted that the strophiole became raised and golden after microwave exposure. They interpreted this as indicating a change in its structure, most probably caused by heating. Pl. 23 shows the hilum and strophiolar region of *A. suaveolens* after microwave exposure during which the seed was heated to 100°C; the surface crack pattern which also developed is shown in Pl. 24. However, the cracks apparently play little role in water imbibition; when the strophiole of treated seed was covered with petroleum jelly and seeds were then soaked in water, no seeds swelled. Seed from the same batch with strophiole uncovered gave between 60% and 70% germination. Germinating seeds almost invariably swell from the hilum end and take up to 24 hours to completely imbibe. Nicked and heavily acid-scarified seeds swell most rapidly, while boiling water, dry heat and microwave energy treatments are usually

TABLE 5  
SITES OF INITIAL WATER ENTRY AFTER VARIOUS SEED COAT TREATMENTS

TREATMENT	SITE(S) OF ENTRY	REFERENCE
Boiled 1 - 10 mins.	Unlocalised areas of seed coat	Brown & Booysen (1969) Al-Saadawi and Abdul-Wahab (1977)
Boiling water poured over seed	Strophiole	Cavanagh & Tran (1979)
Dry Heat " "	Predominantly lens. Strophiole	Brown & Booysen (1969) A. Cavanagh (unpub.)
Microwave heating	Strophiole	Tran & Cavanagh (1979)
Organic solvents (a) Acetone (b) Ethanol (c) Methanol	Probably lens area Hilum and/or lens Random areas of coat	Brown & Booysen (1969) " " " " " "
Natural weathering	Rapheole	Robbertse (1974)



PLATE 23

Scanning electron micrograph of seed treated by microwave heating. Note swollen appearance of strophiole.

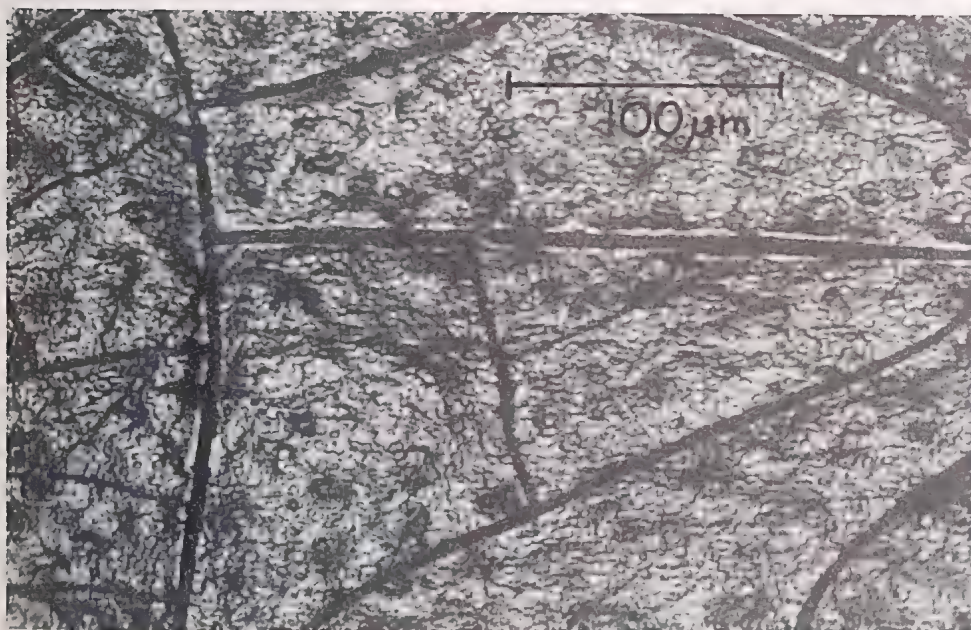


PLATE 24

Surface crack pattern developed by microwave heating.



somewhat slower in action. Heating causes a breakdown of the shortened palisade cells covering the vascular bundle at the strophiole; water penetration can then occur. However, the rate of water imbibition is restricted, at least initially, by the small diameter of the strophiole, typically 0.1 mm in *A. longifolia*. It is possible that once some swelling has commenced, the seed coat becomes softened and permeable at random sites on its surface.

### STORAGE AFTER TREATMENT

The prevailing notion about treated seed is that it cannot be stored but must be sown immediately (Hockings 1975, Turnbull 1972, Western Australia Wildflower Society 1973). This is probably related to the fears expressed by Wycherley (1960) '... unless (the seeds) are rapidly dried after treatment, *before germination commences* (italics mine) the absorbed water allows germination in the field even if there is inadequate moisture in the soil. Complete loss may result if rain fails after sowing.' Just how far the germination process can proceed before drying out induces death of the embryo is not known. Preece (1971b) showed that in *A. aneura*, providing the time between desiccation and re-wetting was of no more than 24 hours duration, the seed can be dried out after germination has commenced and after the radicle has begun to extend, and will resume growth when moisture is available. Knowledge which would be of important practical value in large scale seeding programmes is the age at which a part-germinated seed loses its ability to revive after drying out, and the time interval between drying out and re-wetting which proves fatal.

Harding (1940), Isikawa (1965), Moffatt (1952) and Osborn and Osborn (1931) have established that seed dried after boiling water treatment can be safely stored for long periods with no loss of viability. In fact the Osborns showed that stored seed invariably had an improved germinating ability over freshly treated material. They also dispelled the notion that seed should be boiled or soaked till soft or swollen '... the general physical appearance of the majority of seeds remains unchanged by normal treatments with boiling water.' Their findings were corroborated by Harding (1940) who concluded:

- (1) Boiling accelerates germination considerably but is detrimental after a period of five seconds.
- (2) There is no justification for prolonged soaking.
- (3) Storage for considerable periods is quite practical.
- (4) For any extensive sowing programme, the seed can be treated in advance and stored until required instead of being treated and sown wet in the field.

In experiments aimed at determining the length of time treated seed remained viable, Isikawa (1965) demonstrated that *A. mearnsii* seeds boiled for five

minutes gave a consistent 75-85% germination after two years storage at room temperature; seed held at 5°C lasted nearly three years. Times of boiling ranging from 15 seconds to five minutes had no significant effect on storage life. Acid-scarified seeds of *A. senegal* were stored for six months with no loss in viability (Cheema & Qadir 1973) and several months successful storage has also been achieved with *A. longifolia* after microwave treatment (A. Cavanagh unpublished).

Moffatt (1952) believed that storage had a beneficial effect in allowing 'recovery' of seed whose germination was impaired by boiling or prolonged heating and which gave relatively poor results when sown immediately. He suggested that some substance, possibly an enzyme, might be partially destroyed and required time to be replaced, so allowing normal germination rates to be regained.

### CONCLUSION:

In common with germination studies in other species, there has been insufficient fundamental work carried out on Acacias. In general, most investigators have been concerned with finding a means of improving germination rather than with understanding the mechanism(s) which control the germination process. With the possible exception of *A. mearnsii* no single species has been systematically studied, though for several economically important trees, there is much accrued general ecological information. Surprisingly few attempts have been made to establish optimum treatment conditions even for widely grown species and this situation should be remedied. Serious consideration should be given to investigating the use of 'green' seed where possible as this may obviate the need for seed coat treatment. More use could also be made of biochemical and metabolic data (currently almost non-existent) as this could prove useful in determining the onset of embryo damage in seeds which have been heated or allowed to dry out after partial germination.

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# STUDIES ON WESTERN AUSTRALIAN PERMIAN BRACHIOPODS

## 1. THE FAMILY ANOPLIIDAE (CHONETIDINA)

By N. W. ARCHBOLD\*

**ABSTRACT:** The Family Anopliidae is reviewed and divided into two subfamilies: Anopliinae Muir-Wood and Caenanopliinae subfam. nov. New representatives of the family from the Permian sequences of the Carnarvon Basin, Western Australia, are *Tornquistia occidentalis* sp. nov., *Tornquistia magna* sp. nov., *Tornquistia* sp. aff. *tropicalis* Grant and *Demonedys granti* sp. nov.

### INTRODUCTION

A study of Permian chonetid brachiopods from Western Australia has revealed representatives of the Anopliidae belonging to *Tornquistia* and *Demonedys*. These plus the several new genera since Muir-Wood's (1962) monograph on the Chonetidina have led to a review of the phylogeny of the group.

The new species described herein from Western Australia come from the Carnarvon Basin. The Permian stratigraphic succession of the Carnarvon Basin has been elucidated and reviewed by Condon (1967) and Playford *et al.* (1975), with some changes in nomenclature by van de Graaff *et al.* (1977). It is not proposed to review the stratigraphic sequence further here.

### COLLECTIONS

Registered number prefixes refer to the following institutions: CPC—Commonwealth Palaeontological Collection, Bureau of Mineral Resources, Geology and Geophysics; GSWA—Geological Survey of Western Australia; MUGD—University of Melbourne, Department of Geology.

### TERMINOLOGY

Terminology applied to the Chonetidina in this paper follows Muir-Wood (1962, 1965). Internal structures of the dorsal valve of anopliid brachiopods are critical to their correct generic placement. The important criteria are the presence or absence, in varying combinations, of three structures, namely: 1. the lateral septa (Muir-Wood 1962, p. 21, or anderidia of Sadlick 1965, p. 157-159), 2. the accessory septa, 3.

the median septum. Additional septa and rows of papillae may also be present in the dorsal valve.

### PHYLOGENY

The inferred phylogeny and generic ranges of the Family Anopliidae are shown in Fig. 1. Detailed generic morphology is reviewed under 'Systematic Palaeontology'. It is considered that the family includes two basic stocks (herein defined as subfamilies) one being characterized by smooth shells, the other by costate shells. Variations in external shell shape between genera is probably related to environmental factors and hence similar gross morphologies developed in each stock at different times. Examples of such heterochronous homeomorphy are: 1. a distinct ventral sulcus in *Chonetina* (smooth shell, Late Carboniferous) and in 'New Genus' (costate shell, Late Artinskian); 2. a distinct ventral fold in *Demonedys* (smooth shell, Late Artinskian) and a possible new genus typified by *Chonetella dubia* Loczy, 1897, p.69, text-fig. 16 (costate shell, Late Carboniferous).

The inferred phylogeny for Silurian to Early Middle Devonian anopliids is based largely, on that suggested by Boucot and Harper (1968, p.146) with the addition of *Austronoplia* Isaacson 1977. The author is unaware of any members of the family having been recorded from Eifelian or Givetian deposits. However the costate stock reappears in the Frasnian with the genus *Corbicularia* Lyashenko from the Russian Platform, and a representative of *Globosochonetes* (*G. mathesonensis*, Roberts 1971, p.74, pl.8, figs.1-10) from northwestern Australia, while the smooth stock reappears in the Famennian with specimens referred to *Tornquistia* by Gallwitz (1932, pl. 8, figs. 8-10). Gallwitz also figures at least one costate specimen (pl. 8, fig. 11).

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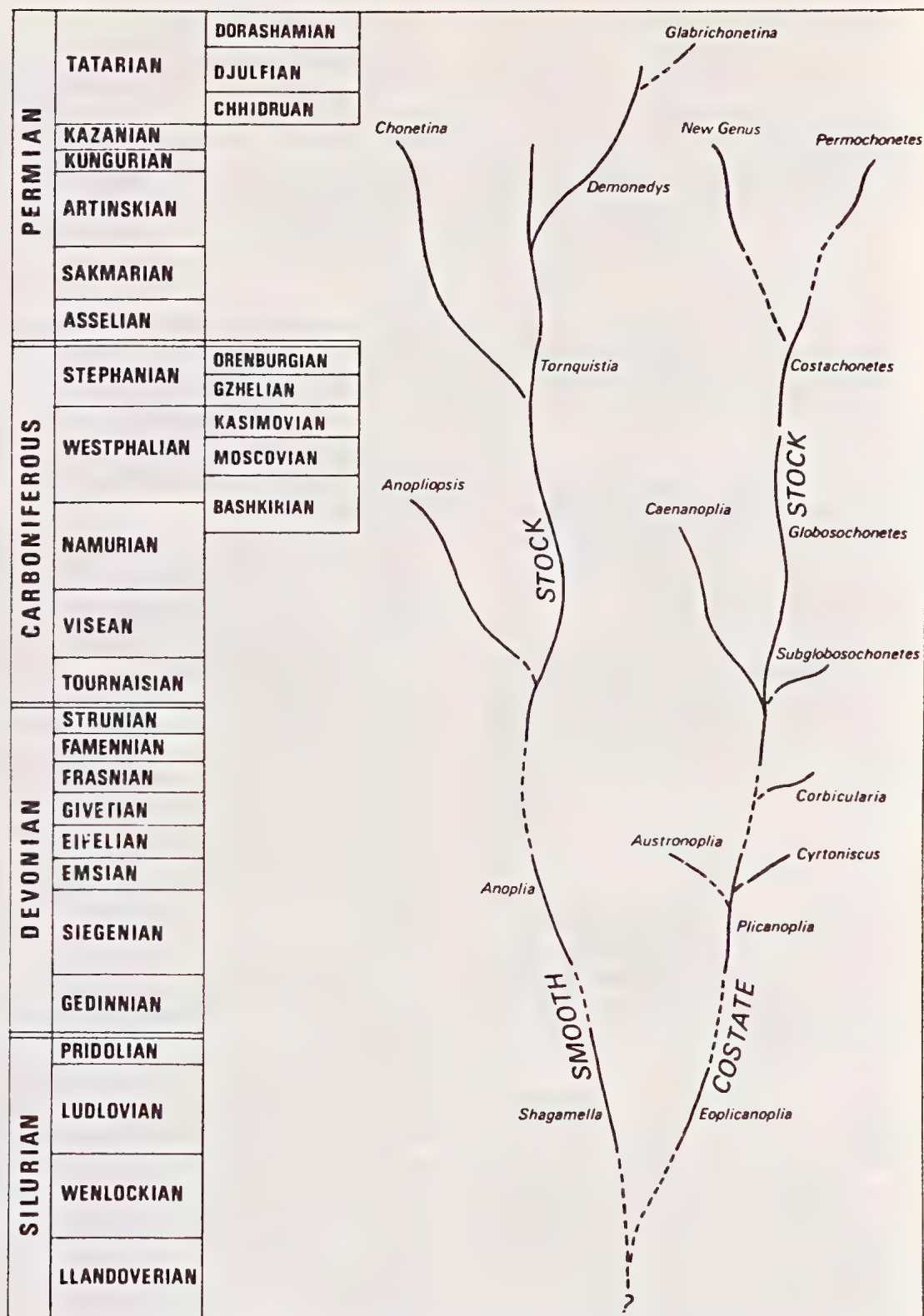


FIG. 1 — Inferred phylogeny of the Family Anopliidae Muir-Wood. The time-scale is used as a reference; no comment on a preferable Late Palaeozoic Stage nomenclature or stage duration is intended. Stages are shown as being of varying duration; for the Permian these will require alteration as more radioactive decay dates become available (see Waterhouse 1978b for a recent review of available data). Horizontal distances between genera do not imply degree of similarity. However, broken lines do indicate intermediate morphologies yet to be found.

In the costate stock, *Globosochonetes* Brunton ranges from Famennian into the Moscovian (Winkler-Prins 1970, p. 39). Arising from *Globosochonetes* in the Early Carboniferous are the forms *Caenanoplia* Carter and *Subglobosochonetes* Afanas'yeva, by modification of the internal dorsal structures. *Costachonetes* Waterhouse appears to arise in the Moscovian (Chao 1928, Rakovec 1932, Ivanov & Ivanova 1936) with the development of a weak, posteriorly developed, ventral sulcus. It ranges into the Early Permian (Yanagida 1967). More varied genera arise later in the Permian: *Permochonetes* Afanas'yeva and 'New Genus' (illustrated by Grant 1976 pl. 12, figs. 1-9). An additional development (not shown in Fig. 1), possibly from *Globosochonetes* is indicated by a form illustrated by Loczy (1897, p. 67, text fig. 16) as *Chonetella dubia*. This form, traditionally placed in the synonymy of *Costachonetes pygmaeus* (Loczy), see Chao (1928, p. 19), possesses a well developed ventral fold and hence, in external morphology, is a homeomorph of the smooth genus *Demonedys* Grant. It should be noted, as Chao (1928, p. 21) clearly described, that in a given population of anopliids considerable variation can occur in the morphology of the ventral valve; this feature is also noted herein for the population of *Tornquistia occidentalis* sp. nov. However, all of Chao's illustrations of ventral valves of *Costachonetes pygmaeus* (Chao 1928, pl. 1, fig. 11a; pl. 2, figs. 1c and 2a) exhibit, a very weak, posteriorly developed, ventral sulcus as do illustrations of the species by Rakovec (1932, pl. 3, figs. 11 and 14), Ivanov and Ivanova (1936, pl. 2, figs. 14-16) and Yanagida (1967, p. 87, pl. 20, fig. 2). The occurrence of *Chonetes pygmaeus* in horizons of Gzhelian age of the Kuibyshev region reported by Semenova (1963, pp. 73-74, pl. 9, fig. 1), if correct, indicates a form with a well developed sulcus. On the other hand Loczy's figures of *Chonetella dubia* do not indicate any development of a ventral sulcus. A similar form is the *Chonetes pygmaeus* var. *asinuata* of Yungerman (1948, p. 40, pl. 1, fig. 4) from Late Carboniferous strata of the Donetz Basin.

The smooth stock reappeared in the Famennian with *Tornquistia* Paeckelmann which ranges into Kazanian times (Waterhouse 1976, p. 13). Off shoots from the long lived *Tornquistia* stock were: *Anopliopsis* Girty in the Early Carboniferous, by modification of the dorsal internal structures, *Demonedys* Grant in the Early Permian, by development of a prominent ventral fold and *Glabrichonetina* Waterhouse in the Late Permian, possibly developing from *Demonedys*. Less clear is the development of *Chonetina* Krotov in the Stephanian (Böger & Fiebig 1963, p. 147-148). *Chonetina*, as discussed below, is herein interpreted as being a smooth genus.

## SYSTEMATIC PALAEOONTOLOGY

SUBORDER CHONETIDINA Muir-Wood, 1955

SUPERFAMILY CHONETACEA Bronn, 1862

FAMILY ANOPLIIDAE Muir-Wood, 1962

(nom. transl. Boucot and Harper 1968, p. 167 ex Anopliinae and Muir-Wood 1962, p. 32, 53).

**DIAGNOSIS:** Small, strongly concavo-convex chonetaceans, smooth or costate, with the presence, absence or differing combination of three internal structures of the dorsal valve, namely the lateral septa, accessory septa and the median septum. Median septum usually less well developed than accessory septa. Origin of the median septum is anterior to the origin of the lateral septa. Pseudodeltidium and chilidium may be present.

**DISCUSSION:** Since raised to family status by Boucot Harper (1968), an event foreshadowed by the numerical study of chonetids by Rowell (1967), the content of the family has increased by nine genera. Winkler-Prins (in Martinez Chacon & Winkler — Prins 1977, p. 11) noted the desirability of subdividing the family. The present study has indicated that the fundamental feature of external ornament, presumably reflecting a function of the mantle edge during growth of the shell, is a reasonable criterion for distinguishing two major groups or stocks within the family. It can be noted that internal structures, especially those of the dorsal valve are very variable from genus to genus and do not permit, at this stage, any readily apparent subgroupings to be differentiated. The content of the two subfamilies of the Anopliidae — Anopliinae Muir-Wood, 1962 and Caenanopliinae subfam. nov. — are discussed below. There are, however, three other genera of chonetid brachiopods that deserve some comment as they possess features reminiscent of the Anopliidae. The genus *Trichonetes* Roberts (1976, p. 22, pl. 3, figs. 10-21) was placed by him, with a query in the subfamily Strophochonetinae. Roberts considered that despite the presence of twin septa in the dorsal valve the genus could not be placed in the Anopliidae because of its 'large size, transverse outline and low concavo-convex profile'. While the genus is not included in the Anopliidae in this study it is noted that the inclusion of the Early Permian genus *Permochonetes* already extends the traditional view of the family particularly with respect to size and profile. Another problem genus is *Airtonia* Cope, 1934. This genus, placed by Muir-Wood in a subfamily by itself is convergent in its dorsal interior structures with the anopliids (Rowell 1967). As yet, however the genus has not been shown to possess the row of ventral spines — characteristic of all members of the Anopliidae — and therefore the author agrees with Muir-Wood (1962, p. 96) and retains the genus in the family Daviesiellidae Sokolskaya, 1960.

Racheboeuf (1976, p. 68) described the genus *Davoustia* in the family Anopliidae. However the row of pits along the internal edge of the ventral interarea and the barely visible corresponding denticles of the dorsal valve make the inclusion of *Davoustia* in the Anopliidae difficult unless, as suggested by Racheboeuf (p. 69), the genus belongs to a distinct new subfamily.



## SUBFAMILY ANOPLIINAE Muir-Wood 1962

DIAGNOSIS: Small, strongly concavo-convex anopliids possessing a smooth external shell.

GENERA INCLUDED: *Anoplia* Hall and Clarke, 1892, p. 309; type species *Leptaena? nucleata* Hall, 1857, p. 47-48. *Anoplia* encompasses smooth anopliids with lateral septa and prominent accessory septa in the dorsal valve. The genus has been well reviewed by Boucot and Harper (1968, p. 168).

*Shagamella* Boucot and Harper, 1968 type species *Shagamella ludloviensis* Boucot and Harper, 1968, p. 168, pl. 29, figs. 4-12. *Shagamella* includes smooth anopliids possessing lateral septa with, at times, a median septum and faint or absent accessory septa in the dorsal valve.

*Anopliopsis* Girty, 1938, p. 281; type species *Chonetina subcarinata* Girty, 1926, p. 27, pl. 5, figs. 10-16. *Anopliopsis* encompasses smooth anopliids, with the development of a very narrow shallow ventral sulcus. Internally the dorsal valve possesses very small lateral septa (Girty 1938, p. 280, fig. 13), long accessory septa with many additional septa inserted between the lateral septa and the accessory septa. Median septum weakly developed anteriorly or absent. This genus has recently been reviewed by Martinez Chacon and Winkler-Prins (1977, p. 11). *Anopliopsis* occurs in Texas, Tennessee and Oklahoma (U.S.A.) and Mere, Spain. The occurrence of *Anopliopsis* in Asia (Transbaykal) recorded by Kotlyar Popeko (1967, p. 91, pl. 15, fig. 13-15) has not been reliably established according to Afanas'yeva (1975, p. 4).

*Chonetina* Krotov, 1888, p. 500; type species *Chonetella artiensis* Krotov, 1885, p. 255, pl. 4, figs. 16-18. *Chonetina* includes smooth anopliids, which possess a narrow strongly developed ventral sulcus and strongly developed accessory and additional septa in the dorsal valve. This genus is restricted to smooth forms in the present study in contrast to Grant (1976) and others. Grant noted the disagreement between Krotov's (1885) figures, which indicate costae, and his descriptions, which specifically state that the shell is smooth, as had Muir-Wood (1962, p. 57) and Ramsbottom (1953, pp. 13-14). Ramsbottom examined topotypic ventral valves in the British Museum and found them to be smooth. Muir-Wood (1962) defined the genus as being smooth but included costate forms within the genus. Boucot & Harper (1968, p. 167) also defined the genus as being smooth. Specimens of *Chonetina* figured by Mironova (1960, pl. 1, figs. 1-3; 1964, pl. 1, figs. 1-3) and Ifanova (1972, pl. 2, figs. 10-22) from the Petchora Basin in northern Russia are all smooth as are specimens from northeastern Russia figured by Afanas'yeva (1977b, pl. 1, figs. 1-2). Fredericks (1925, pl. 1, figs. 54-57) figured several internal moulds of ventral valves from the Soviet Far East. The ventral valve figured by Sokolskaya (1960, pl. 33, fig. 6) as *Chonetina artiensis* is smooth except for two or three radial crenulations near the anterior margin of the left flank, but these do not appear to be true costae; they do not extend to the posterior of the valve. Afanas'yeva (1978a, p. 105) from a study of topotypic material confirms the smooth nature of the genotype of *Chonetina*. Several recent monographs (e.g. Dunbar 1955, Gobbett 1964) have incorrectly attributed species to *Chonetina*.

*Chonetina noenygaardi* Dunbar, 1955 (p. 67) is

striate and the interior structures are unknown — this species is probably a *Chonetinella*. *Chonetina superba* Gobbett, 1964 (p. 118) is costate and flattish in profile. No internal views were figured. The costate specimens illustrated by Grant (1976, pl. 12, figs. 1-19) as *Chonetina* sp. indet., are regarded as being representatives of a 'New Genus' belonging to the Caenanopliinae subfam. nov.

*Glabriconetina* Waterhouse, 1978a, p. 130; type species *Glabriconetina kuwaensis* Waterhouse, 1978a, p. 131, pl. 25, figs. 5, 6, 8, 10-15. This genus includes smooth anopliids with a slightly swollen ventral valve and almost flat dorsal valve. The dorsal interior is characterised by several rows of pustulose septa. The ventral valve exhibits a long median septum.

?*Tornquistia* sp. nov. of Campbell and McKelvey (1972, p. 31, pl. 2, figs. 13-17), may represent a new anopliinid genus although, as those authors state, their specimens are not adequate to stand as type material. Their specimens indicate a large, smooth anopliinid with a distinct, though shallow, ventral sulcus. Providing both valves lack radial ornament, the species may be mid-way between *Tornquistia* and *Chonetina*.

Genus *Tornquistia* Paeckelmann, 1930  
(= *Paeckelmannia* Licharew, 1934, p. 509)

TYPE SPECIES: *Leptaena (Chonetes) polita* McCoy, 1852(= *Leptaena (Chonetes) polita* McCoy 1854, 1855).

DIAGNOSIS: Anopliinids with short lateral septa and prominent accessory septa in dorsal interior. Ventral interior with short thin median septum. Ventral valve swollen, strongly convex.

DISCUSSION: Since the discussion of Muir-Wood (1962, pp. 58-62) and the refiguring of the lectotype (Brand, 1970, pl. 8, fig. 3) this genus has been well understood. The genus appears to have a substantial geological range — Famennian to Kungurian. Many species of chonetid brachiopods with smooth ventral valves from Permian deposits have been referred to *Tornquistia* or *Paeckelmannia*. Gobbett (1964, p. 120, pl. 15, figs. 7-18) referred three species, including *Chonetes capitolinus* Toulou, 1875b to *Paeckelmannia*. *C. capitolinus* is now the type species of *Svalbardia* Barkhatova (1970, p. 78). Gobbett's illustrations, including his figure of the dorsal internal structures (1964, pl. 15, fig. 13), indicate none of his material is of anopliid affinity. Dunbar (1955, p. 68-69) also discussed *Paeckelmannia*; however his specimens, while being smooth, possess a dorsal interior comparable with *Svalbardia capitolinus* (Toulou). Other species externally homeomorphic with *Tornquistia* include *Chonetes novozemlianus*.

Licharew (in Miloradovich 1936, p. 42 and Licharew and Einor 1939, p. 25), now placed in the genus *Eolissochonetes* Hoare, 1960 by Sokolskaya, 1970, p. 76, and *Chonetes rotundatus* Toulou, 1875a, referred to *Lissochonetes* by Ifanova 1972. From the available information it thus appears that the distribution of the genus *Tornquistia* in the Permian is somewhat restricted, being found in Western Australia, Thailand (Grant 1976), possibly the Salt Range, Pakistan (in the form of *Chonetes ambiensis* Waagen, 1883), Eastern Siberia (Zavodowsky 1960, 1971 and Afanas'yeva 1977b) and the Yukon region of Arctic Canada (Bamber & Waterhouse

1971). At least three Permian species are present in Western Australia.

***Tornquistia occidentalis* sp. nov.**  
(Pl. 25, Figs. 1-4; Figs. 2-3)

**MATERIAL:** 14 conjoined shells, 3 isolated ventral valves, 2 internal moulds of ventral valves. One specimen was sectioned to reveal the internal structures.

**LOCALITIES:** a. CPC 19127. Bureau of Mineral Resources Field Number GW78. Basal bed of Callytharra Formation, Callytharra Springs. Lat. 25°52'; Long. 115°30'. b. GSWAF 10995-11005. GSWA Sample No. 44559. Glenburgh Map Sheet. Yard Grid ref. 356 793. Callytharra Formation. c. MUGD 5191-5192. Locality P.498, Callytharra Formation, Callytharra Springs (G. A. Thomas measured section) about 38 metres from base of section. d. MUGD 5193-5194 — Locality P.501, Callytharra Formation, Callytharra Springs (G. A. Thomas measured section) about 42 metres from base of section. e. MUGD 5195. Locality 5664, Callytharra Formation, Bidgemia Station. (G. A. Thomas measured section) about 8.4 metres from base of section.

**MEASUREMENTS:** (in mm), Holotype CPC 19127 (a complete shell).

Specimen Number	Length	Hinge Width	Mid-Width	Thickness
CPC 19127	7.1	8.8	8.2	2.9
GSWA F 10995	6.6	8.2	8.5	3.4
GSWA F 10996	6.9	—	7.4	3.5
GSWA F 10997	5.8	8.8	8.1	2.1
GSWA F 10998	6.3	9.8	9.0	3.2
GSWA F 10999	7.2	11.2	9.7	3.4
GSWA F 11000	7.1	10.2	9.1	3.6
GSWA F 11001	7.2	—	9.7	3.1
GSWA F 11002	—	10.1	8.8	—
GSWA F 11003	6.1	8.8	8.4	3.2
GSWA F 11004	6.9	12.0	11.2	—
MUGD 5191	7.5	11.2	10.0	3.5
MUGD 5192	—	10.5	9.4	—
MUGD 5193	8.0	11.2	9.7	—
MUGD 5194	6.8	10.4	9.7	—
MUGD 5195	7.6	11.0	10.2	—

**AGE:** Early Permian, Sakmarian Stage, Sterlitamakian Sub-stage.

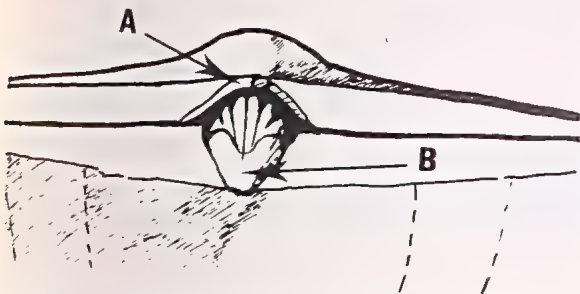


FIG. 2 — Ventral and dorsal interareas and cardinal process of *Tornquistia occidentalis* Drawn from Holotype  $\times 18$ . A Pseudodeltidium, B = Chilidium.

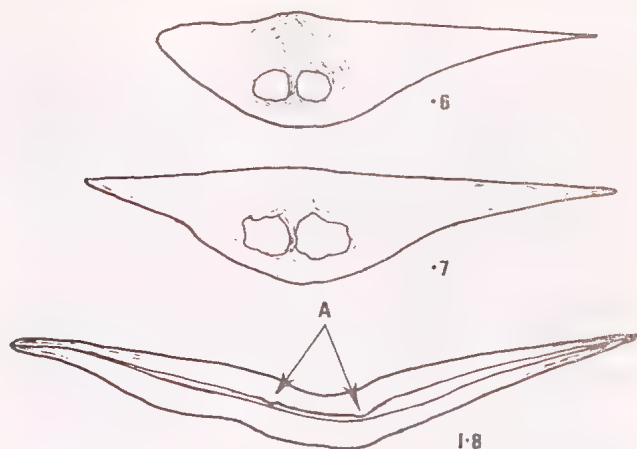


FIG. 3 — *Tornquistia occidentalis* sp. nov. Transverse sections of specimen GSWAF 19005,  $\times 18$ . The numbers refer to the position of the section in mm, from the posterior extremity of the shell. A = Accessory septa. Orientation of calcite fibres shown semi-diagrammatically. Pseudopunctae (taleolae) not shown.

**DIAGNOSIS:** Average sized species for the genus. Convexity of ventral valve, moderate in juvenile individuals, becoming increasingly developed with strongly inflated mesial portion of valve in adult individuals. Dorsal valve deeply concave. Greatest width of shell at hinge. Exterior surface of shell smooth with distinct growth lines. Pronounced ventral interarea twice the height of the dorsal interarea. Cardinal spines short, widely spaced (2.5 mm interval). Ventral umbo sharp and finely pointed.

Ventral interior with large thick teeth. Delthyrium distinct with marked thickening of the shell beneath it. Small pseudodeltidium present in the apex and extending along the sides of the delthyrium. High narrow median septum bisects delthyrium and extends anteriorly as a low delicate structure for half of the valve length. Valve floor—except for weakly impressed muscle area—marked by regularly spaced pustules.

Dorsal interior (deduced from acetate peels) with long accessory septa, no median septum, distinct large alveolus and randomly placed pustules. Small chilidium fused on to external face of cardinal process.

**DISCUSSION:** This species is closest to *T. magna* sp. nov. from which it is distinguished by its smaller size and the remarkable convexity of the latter species. *Tornquistia tropicalis* Grant, 1976, p. 68, is far less convex than the present species. *Tornquistia gibbera* Afanas'yeva, 1977b, p. 12, pl. 1, figs. 12-14, from the Late Carboniferous Paren Horizon of the Kolyma-Omolon region, USSR, is closer in size and convexity although internal structures appear more weakly developed in that species. Also close, although differing in outline, is *T. convexa* Zavodowsky, 1960, p. 63, pl. 1, figs. 2-4; 1971, p. 78, pl. 61, fig. 18, from the Late Permian Omolon Horizon, Kolyma-Omolon Region, USSR. Species recorded from Alaska (Brabb & Grant 1971) and the Yukon (Bamber & Waterhouse 1971) have not been described adequately to warrant close comparison.



***Tornquistia magna* sp. nov.**

(Pl. 25, figs. 5-13)

**MATERIAL:** Two large isolated ventral valves and 2 internal moulds of ventral valves. One block with several hundred isolated valves and conjoined shells has provided many specimens, some of which have been treated with HCl to reveal the internal structures.

**LOCALITIES:** a. CPC 19134-19137, 19139-19141, 19143. BMR Field Number G.279-280. 7½ miles south of west of Moogooree Homestead Lat. 24° 05½'S Long. 115° 06'E. Basal 25 metres of Bulgadoo Shale. b. CPC 19142, 19138. BMR Field number ML 87. Bulgadoo (now Madeline Fm.) lowest fossiliferous horizon. North bank of Lyndon River between Burdghin Murrow and salt pools, 8½ miles from Mia Mia Homestead bearing 82°.

**MEASUREMENTS:** (in mm), Holotype CPC 19137 (internal mould of complete shell)

Specimen Number	Length	Hinge Width	Mid-Width	Thickness
CPC 19142	10.8	13.0	12.4	5.4
CPC 19138	10.3	12.6	—	6.1
CPC 19136	4.5	6.0	—	—
CPC 19135	5.8	9.2	—	—
CPC 19143	7.3	11.4	10.0	—
CPC 19141	6.6	10.4	8.9	—
CPC 19134	7.4	10.0	9.8	—
CPC 19139	7.4	14.0e	11.0	—
CPC 19137	6.2	11.0	9.8	—

**AGE:** Early Permian, Artinskian Stage, Early Baigendzinian Substage.

**DIAGNOSIS:** Shell very large for the genus, semi-circular in outline. Convexity of ventral valves distinct in juveniles and very pronounced in adults. Dorsal valve deeply concave. Greatest width at hinge line. Surface smooth except for very weak growth lines. Interareas low, dorsal interarea very low. Cardinal spines short and blunt. Ventral teeth large and blunt. Delthyrium small. Ventral median septum high posteriorly, low anteriorly, extends as low ridge for posterior half of valve length. Pustules restricted to periphery of valve — Muscle area large but very weakly impressed.

Cardinal process poorly known. Socket plates short but distinct. Lateral septa small. Accessory septa long, extend anteriorly for two thirds of valve length. Several additional, variably developed pairs of septa occur between the accessory septa and the lateral septa. Median septum absent or poorly developed as short ridge between accessory septa. Pustules present around periphery of valve but not abundant.

**DISCUSSION:** The very large size, the very great convexity of the ventral valve, and the strongly inflated mesial portion of the ventral valve distinguish this species. Even relatively juvenile specimens possess the inflated mesial portion of the ventral valve. *Chonetes* sp. of Reed (1930, p. 42-45, pl. 4, fig. 5) from Rio Tayó, Brazil has a ventral valve comparable to the present species in size and convexity. However, no mention is made of internal structures and the dorsal valve is unknown.

***Tornquistia* sp. aff. *T. tropicalis* Grant, 1976**

(Pl. 25, figs. 14-16)

**MATERIAL AND OCCURRENCE:** Three isolated ventral valves, CPC 19128 to 19130, from Minilya River, approximately 14.6 km southeast of Middalya Homestead, 0.2 km north-west of well. The locality carries BMR field number MG 108 and is shown on the Minilya 4 mile geological series map sheet as occurring in the Cundlego Formation.

**MEASUREMENTS:** (in mm)

Specimen Number	Length	Hinge Width	Mid-Width	Thickness
CPC 19128	7.9	—	11.3+	3.1
CPC 19129	6.3	9.2	8.6	1.6
CPC 19130	5.4	—	7.2	1.4

**AGE:** Early Permian, Late Baigendzinian Substage of the Artinskian Stage.

**DIAGNOSIS:** Small to medium sized valves, convexity rather low, mesial portion of valve slightly inflated, greatest width at hinge line. Surface covered in very weak growth lines. Ventral interarea very low. Ventral internal unknown. Dorsal valve unknown.

**DISCUSSION** The little material that is available is clearly distinct from both *T. occidentalis* and *T. magna* both of

## PLATE 25

All figured specimens other than holotypes are paratypes. Magnifications × 3.5 throughout.

Figs. 1-4 — *Tornquistia occidentalis* sp. nov. (1a-d) Shell in ventral, posterior, anterior, and dorsal views, CPC 19127, Holotype. (2a-b) Ventral valve in dorsal and ventral views, MUGD 5191. (3a-b) Ventral valve in ventral and dorsal views, GSWAF 10997. (4a-b) Ventral valve in ventral and anterior views, GSWAF 10996.

Figs. 5-13 — *Tornquistia magna* sp. nov. (5) Internal mould of shell in dorsal view, CPC 19134. (6) Internal mould of shell in dorsal view, CPC 19135. (7) Internal mould of shell in dorsal view, CPC 19136. (8a-c) Internal mould of shell in posterior, ventral, and dorsal valve, CPC 19137, Holotype. (9a-b) Ventral valve in ventral and posterior views, CPC 19138. (10) Ventral valve in ventral view, CPC 19139. (11) External mould of dorsal valve, CPC 19140. (12) Ventral valve in ventral view, CPC 19141. (13a-c) Ventral valve in posterior, anterior, and ventral views, CPC 19142.

Figs. 14-16 — *Tornquistia* sp. aff. *tropicalis* Grant. Ventral valves in ventral view, CPC 19128, 19129, 19130 respectively.

Figs. 17-19 — *Demonedys granti* sp. nov. (17a-b) Ventral valve in ventral and posterior views, CPC 19131, Holotype. (18a-b) Ventral valve in ventral, and posterior views, CPC 19132. (19a-c) Shell in ventral, anterior, and posterior views, CPC 19133.

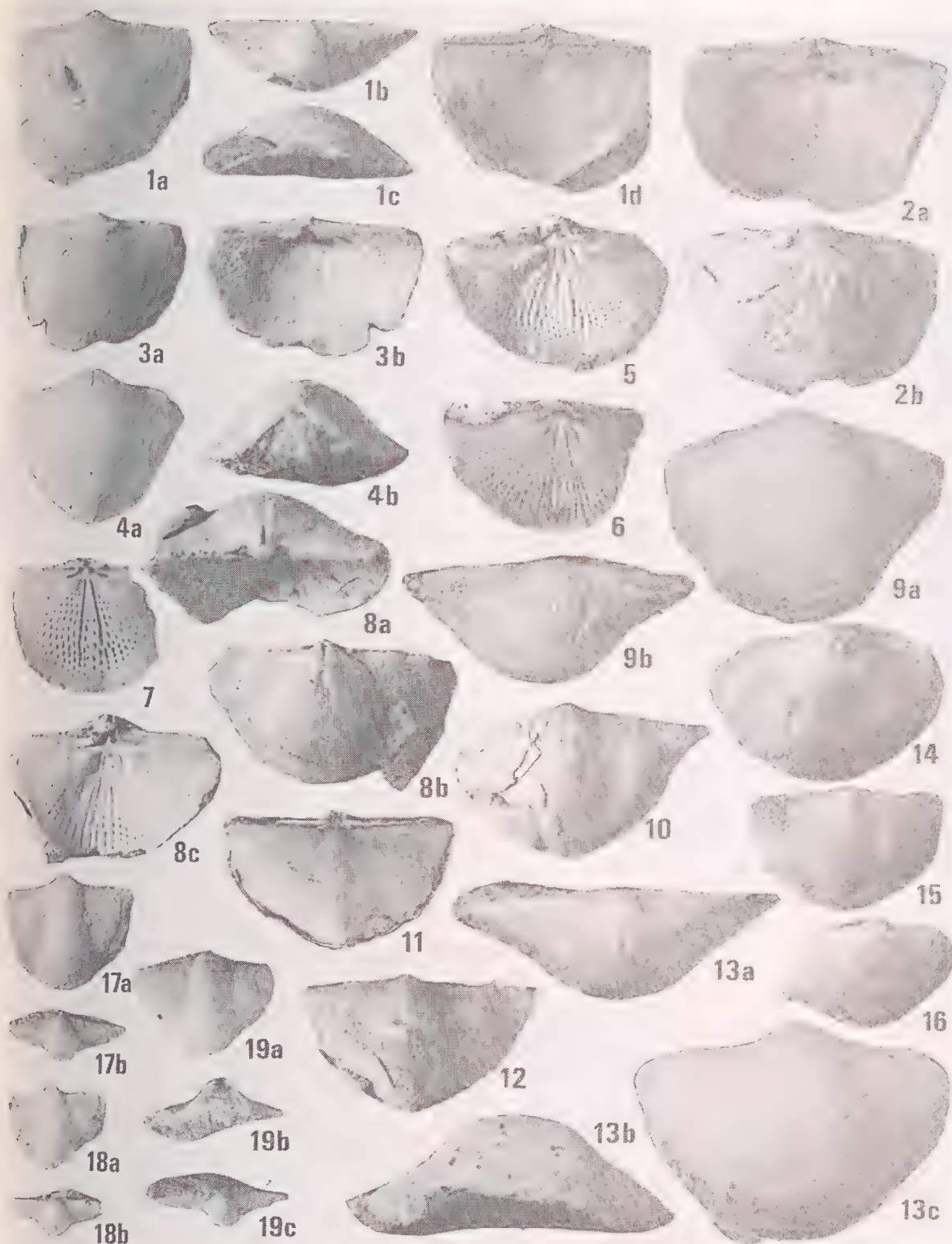


PLATE 25



which exhibit much greater convexity of the ventral valve. These specimens are tentatively ascribed to *T. tropicalis* Grant (1976, pl. 14, figs. 1-11) from Thailand from which they differ only in being uniformly larger.

### Genus *Demonedys* Grant, 1976

TYPE SPECIES: *Demonedys fastigata* Grant, 1976.

DIAGNOSIS: Smooth anopliids with short lateral septa and well developed accessory septa in dorsal interior. Ventral interior with very short median septum. Ventral valve with well developed fold. Dorsal valve strongly concave.

RANGE AND DISTRIBUTION: Since being recognized from the Late Artinskian of Thailand by Grant (1976, p. 66) this genus has been recorded only from the Late Permian of Nepal (Waterhouse 1978, p. 23, 114). It is now described from the Late Artinskian of Western Australia with *D. granti* sp. nov. close to the type species.

### *Demonedys granti* sp. nov. (Pl. 1, figs. 17-19; Fig. 4)

ETYMOLOGY: Named in honour of Dr. R. E. Grant, the first to recognise this striking genus of the Anopliidae.

MATERIAL: Three conjoined shells. One specimen sectioned to reveal internal structures.

LOCALITIES: a. CPC 19131-19133. BMR Field Number MG 108. Minilya River, approximately 14.6 km southeast of Middalya Homestead; .2 km northwest of well. Shown on Minilya 4 mile geological series Map sheet as Cundlego

Formation. b. Poorly preserved specimens referred to *Demonedys granti* sp. nov. are also known from BMR Field Number ML 83, Minilya syncline, north bank of river, 217 feet above base of Wandagee Formation, and also a generalized MUGD Wandagee Formation collection labelled 'Calceolispongia Bed, East Limb of Syncline at Minilya River (material collected by C. Teichert).'

MEASUREMENTS: (in mm) Holotype CPC 19131

Specimen Number	Length	Hinge Width	Mid-Width	Thickness
CPC 19131	6.0	7.7	7.4	2.8
CPC 19132	4.9	6.5	6.1	2.0
CPC 19132	4.4	6.2	5.8	2.0

AGE: Early Permian, Artinskian Stage, Late Baigendzinian substage.

DIAGNOSIS: Small shells. Outline triangular, in juvenile shells, to semicircular, in adult shells. Shells widest at hinge. Ventral umbo, small, sharply curved. Ventral interarea low. Commissure sulcate. Fold arises at ventral umbo, height increases rapidly towards anterior commissure, with strongly curved profile. Growth lines weakly developed posteriorly, more frequently developed anteriorly. Spines along ventral hinge point laterally, spaced every 1.8 to 2 mm. Dorsal valve concave with well developed sulcus. Body cavity narrow with most volume along midline. Cardinal process fills ventral delthyrium.

Ventral interior with short high median septum posteriorly; septum occupies slot between halves of bilobed

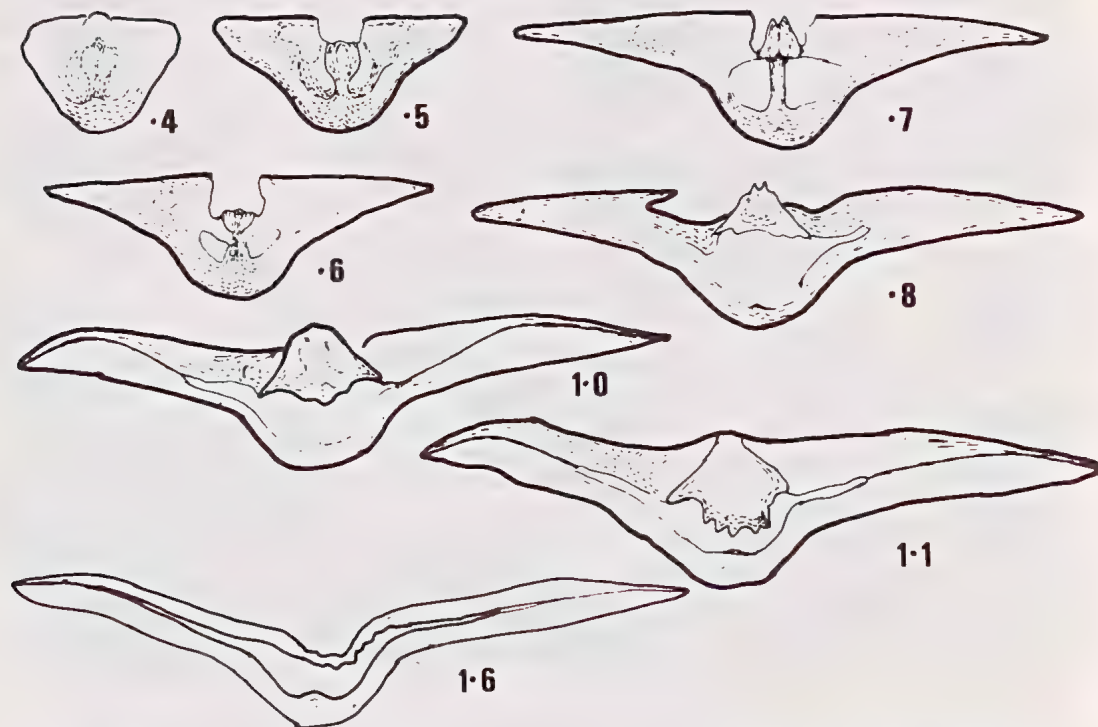


FIG. 4—*Demonedys granti* sp. nov. Transverse sections of specimen CPC 19133,  $\times 18$ . The numbers refer to the position of the section, in mm, from the posterior extremity of the shell. Orientation of calcite fibres shown semi-diagrammatically. Pseudo-punctae (taleolae) not shown.

cardinal process. Interior postules randomly developed on lateral flanks of valves.

Dorsal interior with well developed large cardinal process, bilobed and grooved. Socket ridges poorly developed. Lateral septa low and poorly developed. Accessory septa well developed on interior of dorsal sulcus, apparently two pairs, extending anteriorly for considerable distance. Internal pustules (taleolae) randomly developed.

DISCUSSION: This species is quite close to *Demonedys fastigiata* Grant, the type species. However that species differs by its more triangular outline, lower ventral fold and apparently flatter dorsal valve. Specimens figured by Waterhouse (1978, pl. 1, figs. 10-12, pl. 22, figs. 8-9) are too poorly preserved to warrant close comparison.

The small smooth *Chonetella? dunbari* of Newell (1934, p. 427, pl. 55, figs. 5a-c) should also be mentioned here. This has a well developed ventral fold and is comparable in size (from the figured specimen) with the largest specimen of *Demonedys granti*. If it was found in a Permian assemblage, rather than mid-Pennsylvanian, in either Western Australia or Thailand, rather than North America, there is little doubt it would be classified as a representative of *Demonedys*. Its internal structures are, unfortunately, unknown.

#### SUBFAMILY CAENANOPLIIDAE subfam. nov.

DIAGNOSIS: Small to medium sized, concavo-convex anopliids with a costate exterior.

GENERA INCLUDED: *Eoplicanoplia* Boucot and Harper, 1968, p. 168; type species *Chonetes colliculus* Foerste, 1909, p. 24-5, pl. 1, figs. 10a-c. This genus includes caenanopliids with lateral septa and a faint median septum in the dorsal valve. The genus was well described and figured by Boucot and Harper (1968, pp. 168-169).

*Plicanoplia* Boucot and Harper, 1968, p. 169; type species *Chonetes fornacula* Dunbar, 1923, p. 130, pl. 2, fig. 25. This genus encompasses costate anopliids with strongly developed lateral septa and accessory septa in the dorsal valve.

*Cyrtioniscus* Boucot and Harper, 1968, p. 172; type species *Chonetes nectus* Clarke, 1907, pp. 263-4, figs. on p. 264. *Cyrtioniscus* includes costate anopliids which have marked discontinuity in the surface of the ventral cal. Lateral and accessory septa are present on the dorsal valve.

*Austronoplia* Isaacson, 1977, p. 178; type species *Chonetes stubeli* Gurich, 1893, p. 80, pl. 5, figs. 3, 4. This genus includes caenanopliids with angular costae as well as lateral septa and a medium septum in the dorsal valve. The interior of the dorsal valve with many prominent rows of papillae resembles the much younger *Permochonetes*.

*Corbicularia* Lyashenko, 1973, p. 29; type species *Chonetes menneri* Lyashenko, 1958, p. 119, pl. 1, figs. 4-11. *Corbicularia* is characterised by small fine costae. The median septum, lateral septa and brachial ridges are all absent.

*Globosochonetes* Brunton, 1968, p. 48; type species *Globosochonetes parseptus* Brunton, 1968, p. 48, pl. 7, figs. 8-27. *Globosochonetes* includes strongly concavo-convex caenanopliids. Strong accessory septa and weak lateral

septa are present on the dorsal interior where a short dorsal median septum may also be present.

*Subglobosochonetes* Afanas'yeva, 1976, p. 307; type species *Chonetes (Rugosochonetes) malevkensis* Sokolskaya, 1950, p. 23, pl. 1, figs. 1-16. The genus is restricted to caenanopliids with no median septum or accessory septa in the dorsal valve. Lateral septa are short.

*Caenanoplia* Carter, 1968, p. 1143; type species *Caenanoplia burlingtonensis* Carter, 1968, p. 1143, pl. 145, figs. 1-26. *Caenanoplia* includes strongly concavo-convex caenanopliids with lateral septa but no median septum or accessory septa in the dorsal valve. It is a genus close to *Subglobosochonetes* but is distinguished from that genus by its more trigonal outline and the greater convexity of the ventral valve. This is a more weakly costate genus than others of the subfamily but it is noted that internal moulds of the genus (Carter 1968, pl. 145, figs. 21-22) exhibit radial rows of papillae. The close correspondence between these rows and the external ribbing was noted by Brunton (1968, p. 48).

*Costachonetes* Waterhouse, 1975, p. 2; type species *Chonetes uralica* Möller var. *pygmaea* Loczy, 1897, pp. 64-5, text figs. 13 and 14. This genus includes caenanopliids with a swollen ventral valve which carries a narrow ventral sulcus — at least posteriorly. The dorsal interior carries a thin median septum and small lateral septa (Chao 1928, p. 20, pl. 1, fig. 13).

*Permochonetes* Afanas'yeva, 1977a, p. 138; type species *Permochonetes pamiricus* Afanas'yeva, 1977, p. 138, text figs. 1, 2. This genus includes finely costate shells which are large for the family. Lateral septa, accessory septa and a median septum are absent from the dorsal valve. Rows of radial papillae are present.

'New Genus' was illustrated by Grant (1976, pl. 12, figs. 1-19) as *Chonetina* sp. indet. It appears to be a caenanopliid with lateral septa, accessory septa and a short posteriorly developed median septum in the dorsal valve. Confirmation of the novelty of this material is left to those with access to the Thai material and hence the nomenclature is left open. The concept of *Chonetina* used herein has already been discussed above.

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#### ADDENDA

The genus *Yagonia* Roberts (in Roberts et. al. 1976) from the Visean of New South Wales was inadvertently excluded from the above discussion of the family Anopliidae. It is an extraordinarily large, smooth form and presumably belongs to the subfamily Anopliinae as defined herein. Its phylogenetic relationships to other members of the subfamily are not clear.

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## CLINAL VARIATION IN *Eucalyptus incrassata* LABILLARDIERE

By F. C. JOHNSTONE\* AND N. D. HALLAM\*

**ABSTRACT:** Morphological variation of three closely related taxa of mallee eucalypts (*Eucalyptus incrassata*, *E. angulosa*, and *E. costata*) was examined. Morphological characteristics were quantified from samples collected over a range of environmental conditions in the Murray Mallee of southeastern Australia. Numerical analysis revealed that the three taxa form a continuous series; it is suggested that these taxa represent points in a cline of a single species. Revision of the nomenclature is proposed.

### INTRODUCTION

*Eucalyptus incrassata* Labill., one of the most widespread mallee eucalypts, is found in mallee areas of Western Australia, South Australia, Victoria and New South Wales. Mallee communities, the most arid of the eucalypt-dominated communities of temperate Australia, are predominant between the 25 and 66 cm isohyets (Parsons 1966).

The natural distribution of *E. incrassata* is shown in Fig. 1. Disjunctions occurring on the Nullarbor and Roe Plains have been discussed by Parsons (1970).

The taxon *E. angulosa* Schauer represents a larger fruited form of *E. incrassata* with a more coastal distribution (Chippendale 1973). Its fruits tend to be

more heavily ribbed than those of the smaller, smoother fruited *E. incrassata* (Burbidge 1947, Chippendale 1973) and it usually grows in white coastal sands in areas of 38-66 cm per year mean rainfall. *E. incrassata* occurs also in coastal areas but its range extends into the dryer areas of the Mallee where the average rainfall is 20-50 cm per year (Chippendale 1973).

The distinctions between *E. incrassata* and *E. angulosa* are not clear and identification of many specimens is difficult. As a result there have been many nomenclatural changes since the first description of the taxa in the nineteenth century.

The species *Eucalyptus incrassata* was described (1804) by Labillardière. He designated the type



FIG. 1 — Limits of *E. incrassata* distribution as shown by Parsons (1966), and sites of collections held by Australian Herbaria (Chippendale, unpublished data, 1977). □ *E. incrassata*  
Δ *E. incrassata angulosa*

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specimen from material he collected near Esperance Bay on the southwestern coast of Australia in December 1792 (Boomsma 1969). As with many other groups within the genus *Eucalyptus* many species described later were found to be synonymous with *E. incrassata*. Other forms, thought originally to belong to *E. incrassata* have been given the status of independent species.

The taxon *E. angulosa* is of particular interest as it has alternated frequently between independent species status and inclusion in *E. incrassata*. The taxon *E. costata* Behr. et Muell. ex Miquel is often used as an intermediate or linking form of *E. incrassata* and *E. angulosa*. A brief summary of the major changes of status of the taxa discussed is shown in Table 1.

The confusion regarding the status of the taxa *E. incrassata*, *E. angulosa* and *E. costata* appears to be due to the existence of a number of forms intermediate between each pair of taxa. Maiden (1922) gives examples of these forms, but their nature is unknown. Burbidge (1947) suggests that these taxa probably represent points along a graded series of variants.

The aim of this study was to find the nature of the forms intermediate between the taxa, and the relationships of the taxa themselves. The morphological characteristics of the major plant organs of trees cover-

ing a wide geographic range and encompassing the taxa *E. incrassata*, *E. costata* and *E. angulosa* were examined. Studies of geographic variation have proved useful in the revision of other groups of eucalypts: for example, Kirkpatrick (1974) used a geographic study of the 'blue-gum' group of eucalypts to revise the nomenclature.

To avoid confusion the name *E. incrassata* will be used here to include the taxa *E. incrassata* Labill., *E. costata* Behr. et Muell. ex Miquel and *E. angulosa* Schauer. When referring to the different forms of *E. incrassata* (i.e. typical form, *E. costata* form and *E. angulosa* form) the unattached epithets var. *incrassata*, var. *costata* and var. *angulosa* are used.

## MATERIALS AND METHODS

### STUDY AREA

The study area comprised most of the south-eastern Australian Mallee as shown in Fig. 2. The climate of this region is semi-arid: average annual precipitation varies from 75 cm in the south to 25 cm in the northern extremities near Mildura. The rainfall is unreliable, with a variability (i.e. average deviation from mean annual rainfall as a percentage of the mean average rainfall) of around 30%. In terms of precipitation, evaporation and soil moisture storage there is a trend to increasing aridity moving east from the western extremities and north in the eastern section of the study area. Large areas of the mallee have been cleared for agricultural use and many of the collection sites used in our study were small relict roadside communities adjoining agricultural land.

### SAMPLING METHODS

Trees were sampled at nine sites within the study area (Fig. 2). The number of trees sampled at each site ranged from seven to nineteen. The variation in sample size was due to the nature and size of the stands studied. It was considered an advantage to analyse all of the data gathered rather than to reduce the information by using standard population sizes. Pryor (1956) has suggested that the minimum population size for quantitative morphological studies on eucalypts is five trees. Trees were selected and sampled in a manner similar to that described by Green (1971). Voucher specimens of all samples used are held in the Monash University Botany Department Herbarium.

### MORPHOLOGICAL CHARACTERISTICS

Measurements of adult leaf dimensions and capsule morphology were made for numerical analysis. The following measurements were made on ten randomly-selected capsules from each tree sampled: capsule diameter at half length (FW), diameter of

TABLE 1

A SUMMARY OF THE TAXONOMIC HISTORY OF *E. incrassata* AND CLOSELY RELATED TAXA.

Year	Nomenclature
1804	<i>E. incrassata</i> described by Labillardière, and validly named.
1843	<i>E. angulosa</i> described by Schauer, and validly named.
1855	<i>E. costata</i> described by Behr and Mueller (Mueller, 1855).
1859	<i>E. costata</i> validly named by Miquel.
1866	Bentham used the names <i>E. incrassata</i> Labill., <i>E. incrassata</i> var. <i>angulosa</i> ; <i>E. costata</i> F. Muell. = <i>E. incrassata</i> var. <i>angulosa</i> .
1888	Mueller: <i>E. angulosa</i> Schauer and <i>E. costata</i> Behr et. Muell. both = <i>E. incrassata</i> Labill.
1934	Blakely uses the names <i>E. incrassata</i> Labill. <i>E. angulosa</i> Schauer and a new variety <i>E. angulosa</i> var. <i>ceratocorys</i> ; <i>E. costata</i> Behr et. Muell. is listed a synonym of <i>E. angulosa</i> Schauer).
1947	Burbidge: <i>E. incrassata</i> Labill., <i>E. incrassata</i> var. <i>costata</i> , <i>E. incrassata</i> var. <i>angulosa</i> Bentham.
1969	Boomsma: <i>E. incrassata</i> var. <i>incrassata</i> , <i>E. incrassata</i> var. <i>angulosa</i> Benth; <i>E. costata</i> is included in <i>E. incrassata</i> although the variety is not specified.
1971	Brooker: <i>E. incrassata</i> , <i>E. angulosa</i> no mention of <i>E. costata</i> .
1971	Pryor and Johnson: Both <i>E. angulosa</i> and <i>E. costata</i> are local variants of <i>E. incrassata</i> .
1976	Chippendale: <i>E. angulosa</i> Schauer, <i>E. incrassata</i> Labill., <i>E. costata</i> F. Muell. = <i>E. incrassata</i> Labill.

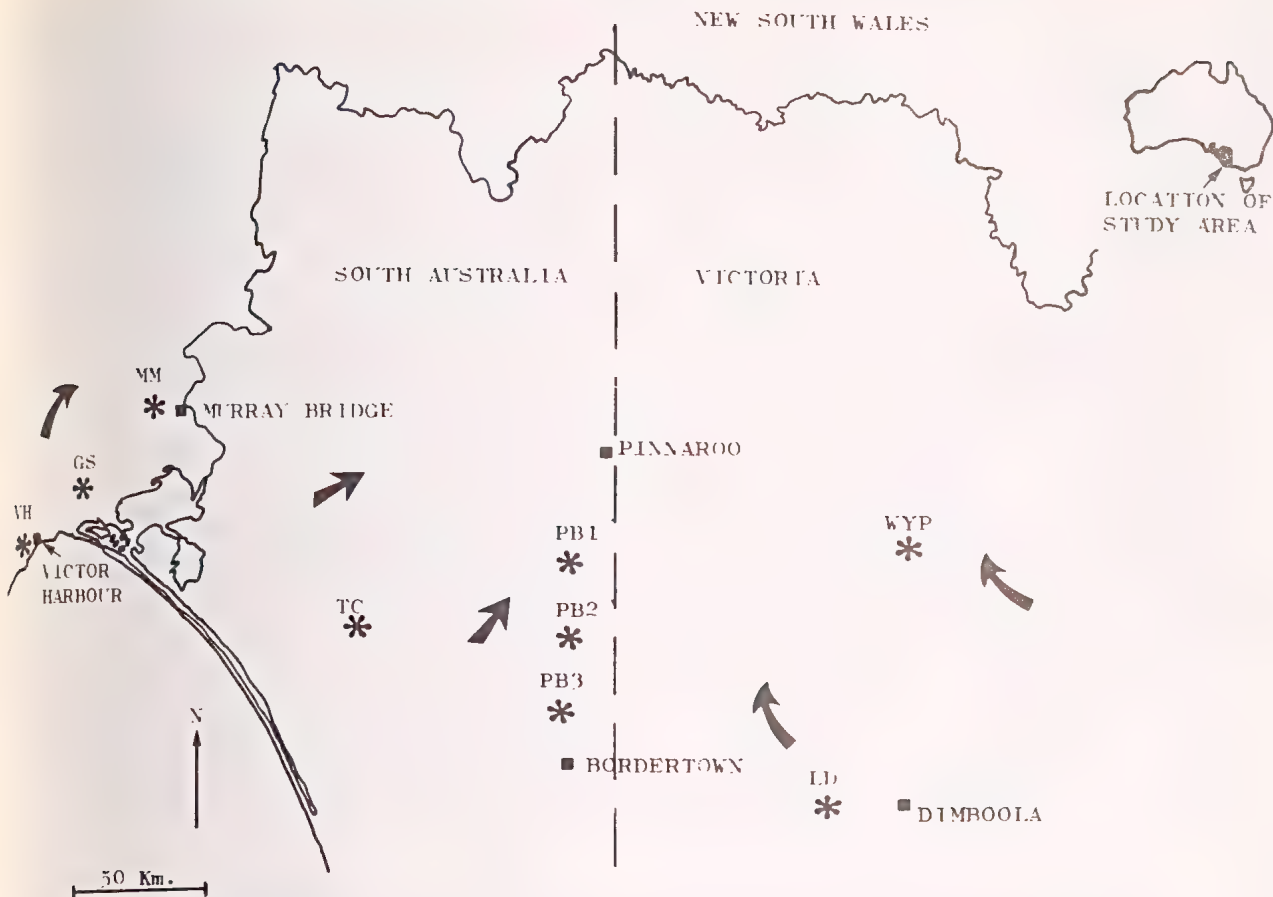


FIG. 2 — Map of the study area showing the location of collecting sites together with their codes e.g. MM. The large arrows indicate the gradient of increasing aridity moving inland. Exact locations of collecting sites are listed in Appendix I.

calyx ring (EW), capsule length (excluding pedicel) (FL), the number of valves per capsule (VN), the relative depth of valves (0 = valves exerted  $\rightarrow$  3 = valves deeply sunken) (VD), pedicel length (PC) and peduncle length (PD) (see Fig. 3). From these characteristics additional derived characters were calculated, these being the following ratios:  $FLW = FL/FW$ ,  $W/E = FW/EW$  and  $C/D = PC/PD$ .

The degree of ribbing or angularity of the fruit surface has been quantified by assigning the following values to character FS (relative angularity of the fruit surface):

- 0 = 'smooth fruit': an absence of any longitudinal lines or ridges;
- 1 = 'striate fruit': longitudinal lines present; the lines are not raised significantly from the fruit surface;
- 2 = 'costate fruit': longitudinal ridges raised significantly above fruit surface, not as tall as broad, usually rounded summit;
- 3 = 'angular fruit': longitudinal ridges raised signific-

antly above fruit surface, as tall or taller than broad, summit often sharp, triangular in section.

Burbidge (1947) used 'striate' to describe longitudinal ridges or lines which are apparent owing to shrinkage of non-sclerotised tissues; 'ribbed' was used when the ridges were deep enough to have been evident on fresh specimens. The implication is that some fruit capsules examined were collected whilst 'green' and have since suffered shrinkage during drying. The drying of fruit detached from the tree often results in a surface pattern not normally seen on fruit which have dried *in situ*. Wrinkling of the surface and more prominent striations are often the result.

In this study all characteristics of the fruit capsules were determined from mature fruits which had dried naturally on the tree. Wherever possible they were collected with the fruit valves open and seed still in the fruit. Old fruits tend to have surface features weathered away.

Morphology of the leaves was assessed by



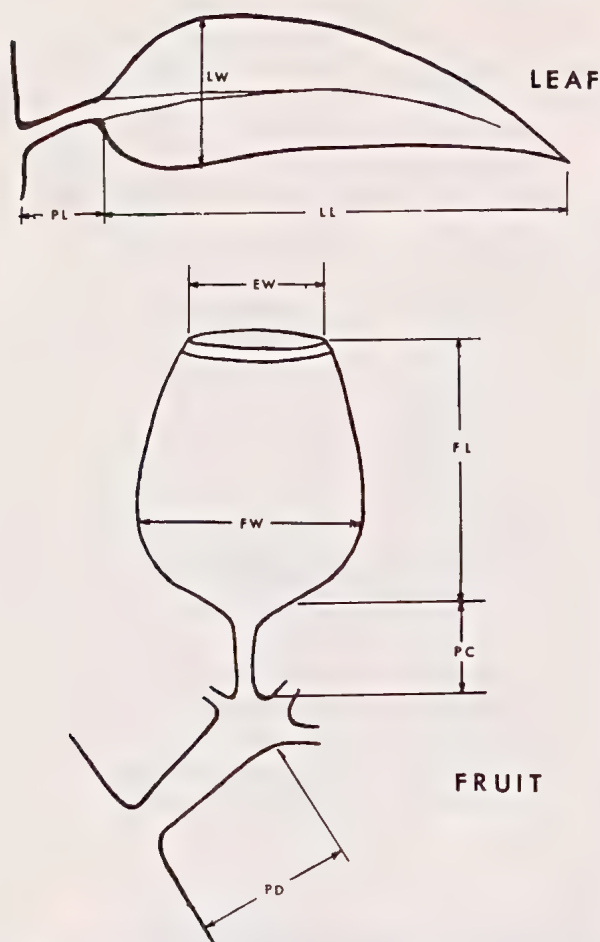


FIG. 3 — Illustration of the morphological characters of the leaves and fruit.

selecting the largest leaves of 10 branchlets from each tree, these leaves being regarded as representative of each tree (Larsen 1965). The following measurements were made on these leaves; leaf blade length (LL), leaf blade width (LW), petiole length (PL) (see Fig. 3). From these characters further ratios were derived;  $L/W = LL/LW$ ,  $L/P = LL/PL$ .

#### ANALYSIS

The morphological data for the trees sampled was analysed using a Burroughs B6700 computer at Monash University and a PDP 10 at La Trobe University.

The following numerical methods were used to analyse the raw data:

i) *Factor Analysis* (Harman 1965), a method of data reduction. The variance of a set of variables is explained in terms of a set of fewer uncorrelated variables (factors). In most cases the number of factors accounting for the total variation is significantly fewer than the number of variables entered into the analysis.

The program 'FACTOR' with Varimax orthogonal rotation (Nie *et al.* 1970) was used in this study. This is an R-mode analysis which uses a correlation matrix. ii) *Analysis of Variance and Student-Newman-Keuls Multiple Range Test (S.N.K.)* (Sokal & Rohlf 1969). Populations were checked for significant F-ratios, and significant differences between population means for each character were determined using the S.N.K. test. Analysis of variance and the S.N.K. test were performed on the data using a computer program described by Adams & Turner (1970).

iii) *Surface Trend Analysis* (Adams 1970). Population means for characters found to differ significantly between populations (using the S.N.K. test) were contoured using Surface Trend Analysis. The program CONTRS 4 (Adams 1970) was used to generate contour gradients for each character. The contours were then superimposed onto a map of the study area. The relationships between populations can then be assessed visually.

iv) *Differential Systematics* (Adams & Turner 1970). Differential systematics is a method which gives an indication of the total trend of several characters at once. Regions of rapid change are detected which indicate regions of differentiation within a taxon. The program DIFFSYS (Adams 1970) was used in this study.

v) *Hierarchical Grouping Analysis*. Hierarchical grouping analysis was used to cluster individual trees into groups whose members were more similar to one another than to any individual outside of the group (Lance & Williams 1967a). Many methods of producing a hierarchical classification are available (Lance & Williams 1967a, 1967b, 1968). The program HGROU (Veldman 1967) was used in this study. This program employs a polythetic, agglomerative strategy based on within-group variance, in contrast to the commonly used similarity measures.

#### RESULTS

The morphological characters measured for *E. incrassata* show considerable variation. The means, standard deviations and ranges of values for the morphological characters are listed in Table 2. From this data and the scatter diagrams (Fig. 4) of selected pairs of variables, considerable variation within the taxon is apparent.

The morphological characters accounting for variation of *E. incrassata* were determined by Factor Analysis. The variation was accounted for by six factors. The percentage of the total variation accounted for by each factor and the characters correlated with each factor (ranked in order of correlation with the factor) are shown in Table 3. This indicates that the

TABLE 2  
MORPHOLOGICAL CHARACTERISTICS OF *E. incrassata*

Code	Character	Mean*	Std. Dev.	Range*
LL	Leaf blade length	90.3	11.5	57.5 — 127.1
LW	Leaf blade width	21.3	3.5	13.9 — 33.4
PL	Petiole length	17.0	2.7	12.0 — 24.0
L/W	LL/LW	4.3	0.7	2.3 — 6.26
L/P	LL/PL	5.4	0.9	3.87 — 8.42
FL	Fruit length	13.5	2.4	7.7 — 22.1
FW	Diameter of fruit at ½ length	10.8	2.0	6.3 — 22.3
EW	Diameter of Calcare ring	9.2	1.6	6.38 — 19.00
PD	Peduncle length	14.2	2.9	7.2 — 22.6
PC	Pedicle length	2.8	1.5	0.42 — 8.07
FLW	FL/FW	1.3	0.15	0.98 — 1.67
W/E	FW/EW	1.2	0.11	0.90 — 1.50
C/D	PC/PD	0.19	0.09	0.00 — 0.67
VN	Average no. of valves per fruit	3.1	0.2	3.0 — 4.0
VD	Relative depth of valves	2.3	1.8	1.0 — 3.0
FS	Relative angularity of fruit	2.1	0.8	0.0 — 3.0

\*Where appropriate all dimensions are in mm.

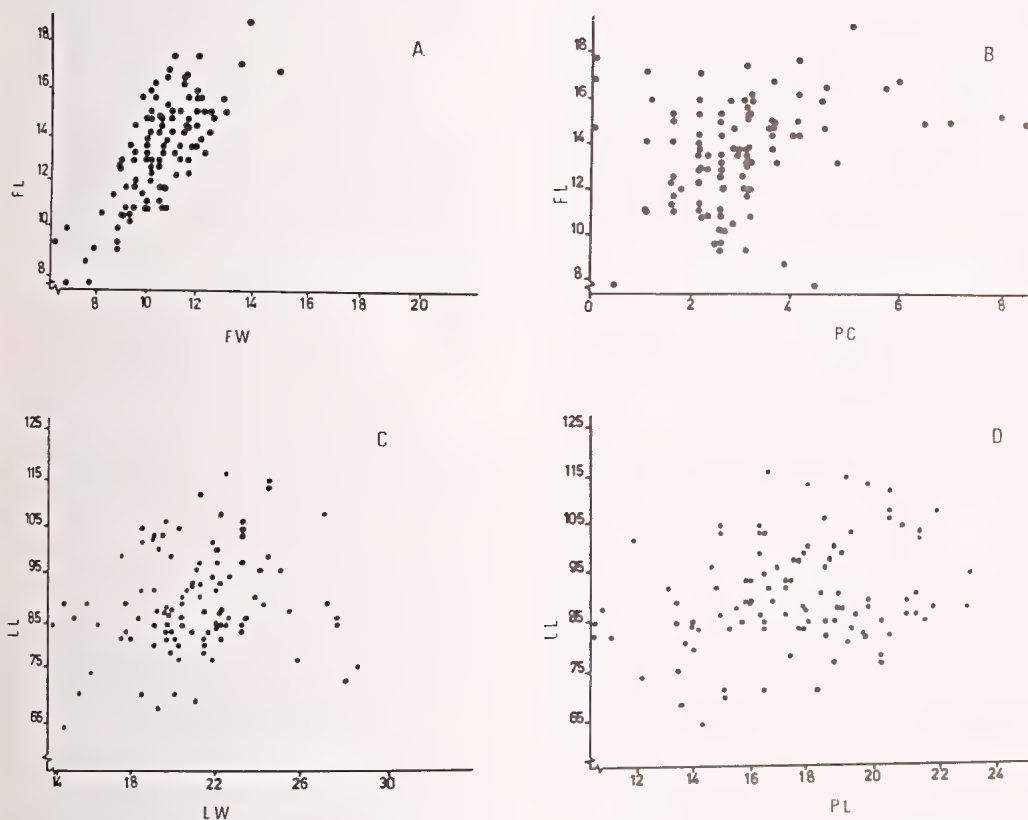


FIG. 4 — Scatter diagrams of several pairs of morphological characters. A. Fruit length (FL) v. Fruit Diameter (FW); B. Fruit length (FL) v. Pedicle length (PC); C. Leaf length (LL) v. Leaf width (LW); D. Leaf length (LL) v. Petiole length (PL). The scale of each axis indicates the length in millimetres.



first character listed for each factor is the best approximation to the factor.

The variation of *E. incrassata* can be accounted for by the characters FL, PC, LW, PL, LL, W/E (in descending order of percentage variation explained). The fruit dimension characters (FL, FW, EW) are highly correlated (all correlated to Factor 1, implying that the general shape of the fruit is similar over the range of fruit sizes. The 'angularity' of the fruit (FS) is also correlated to Factor 1, which implies a correlation between fruit size and 'angularity'. Examination of raw data and specimens collected shows that larger fruit are more angular than smaller fruit. The scatter diagram of FL versus FW (see Fig. 4) shows this correlation between the fruit length and diameter. There is a spread of values orthogonal to the main axis of the scatter, indicating some variability in the length-width ratio of the fruit. The character FLW is correlated to the second factor (Table 3); FLW, a measure of fruit shape, varies independently of the fruit dimensions. The character W/E is a measure of the degree of tapering of the upper half of the fruit. W/E is correlated to the sixth factor (Table 3), and is, therefore, independent of fruit size (FL, FW, EW) and basic fruit shape (FLW). The morphology of the fruit has three independent patterns of variation.

The character PC is correlated to both the uncorrelated characters PD and FLW. The narrow fruit (high values of FLW) tend to have long pedicels and where the pedicel is long there is also a trend towards long peduncles. The ratio between PC and PD (C/D) does not account for any more variation than the pedicel length itself and is highly correlated with PC (pedicel length).

The characters of the leaf vary independently from those of the fruit, with the exception of VN which co-varies with the width of the leaf blade. The three primary characters of the leaf (LL, LW, PL) account for different factors of the variation pattern. The scatter diagrams of combinations of these characters show that although a degree of correlation is evident there is a considerable spread of points orthogonal to the main axis. The lack of correlation between these two charac-

ters was expected as the samples collected showed a wide range of leaf shapes.

The total variation pattern of *E. incrassata* is composed of six independent factors. These are correlated to three independent characters of the fruit (FL, PC, W/E) and three independent characters of the leaves (LL, LW, PL). It is possible for any individual of *E. incrassata* within the study area, to possess a combination of any values in the range of these characters.

The nature of the variation (disjunct, clinal or random) can be assessed by analysis of the variation within and between populations of the taxa over a geographic range.

The morphological characters which have greater variations between populations than within populations were identified by Analysis of Variance and S.N.K. test (using the 0.01 level of significance) (Table 4).

The characters showing significant differences between populations are not the same as those accounting for the total variation pattern (from Factor Analysis). Some of the characters which account for the total variation have a higher variance within populations than between populations. The characters FS, FW, EW (Factor 1); LL (Factor 2); LW (Factor 3) do not show significant differences between the populations using the S.N.K. test.

The results from the S.N.K. test (Table 4) give an indication of a trend. Samples from the Victor Harbor (VH) and Goolwa-Strathalbyn (GS) populations appear to have significantly larger means for many characters than the samples from the Pinnaroo-Bordertown 2 (PB2) population.

TABLE 4  
RESULTS OF THE S.N.K. TEST ON  
*E. incrassata* POPULATIONS

The population codes are listed in order of decreasing magnitude of the population means for the character tested. The lines connect means which have no significant difference. Any two means connected by a single line are regarded as not being significantly different.

Character Tested	S.N.K. Grouping of Populations									
PL	MM	VH	LD	TC	GS	PB1	WYP	PB2	PB3	
L/P	PB3	WYP	TC	GS	PB2	VH	LD	PB1	MM	
FL	GS	VH	MM	PB3	LD	TC	PB1	PB2	WYP	
PC	VH	GS	MM	LD	PB3	WYP	PB1	TC	PB2	
FLW	GS	VH	MM	TC	WYP	PB3	PB2	PB1	LD	
C/D	VH	GS	PB1	LD	MM	WYP	PB3	TC	PB2	
VN	PB3	TC	VH	GS	MM	PB1	WYP	LD	PB2	

TABLE 3  
RESULTS OF *E. incrassata* FACTOR ANALYSIS

Factor	% of Variation Accounted for	Characters Significantly Correlated to Factor
1	30.6	FL, EW, FW, FS
2	21.9	PC, C/D, FLW
3	15.6	LW, L/W
4	12.5	PL, L/P
5	11.7	LL
6	7.6	W/E



The S.N.K. test provides information concerning characters which can be used for further analysis of the populations. Those characters which distinguish populations (and have a significant F value) were used for Surface Trend Analysis, Differential Systematics and Hierarchical Grouping Analysis.

The characters FL, PC, FLW, C/D (Figs. 5D, F, G, H) show definite, simple trends across the study area. Large values for the characters generally occur in the west and small ones in the east. The trends shown by these characters are of particular significance as the characters account for over half of the total variation of the individual samples (from Factor Analysis). The trends in the other characters are more complex. Some populations are quite distinct from those adjacent, causing distortion of the overall trends. The contour plot of FS (Fig. 5J) is an example of this type of map. The Tintinara-Culburra (TC) population (population d on Fig. 5J) is vastly different from any adjacent population. The west-east trend in FS is not obvious due to the influence of the contour lines surrounding population TC. Leaf width, LW (Fig. 5A) produces a complex pattern in which some local trends are detectable but in which there is no general trend across the study area.

The trends shown by the different contour maps were amalgamated using differential systematics. The rates of change between populations of all the character means are plotted as contours (Fig. 6). The number of contour lines between populations is an indication of the rate of change in the characters between the populations: the more lines the greater the change. Fig. 6 shows that there is a considerable rate of change between all populations. On the basis of character means the populations are distinct from one another, and the Surface Trend Analysis and S.N.K. results indicate that there are trends across the study area. Combining these results indicates that there may be a geographic sequence of populations covering the morphological range.

Referring again to the scatter diagrams (Fig. 4) there are no discontinuities in the points plotted. This implies that although the population means are distinct, the ranges of individuals in the populations overlap to such a degree that a continuous cluster of points is formed. This is shown clearly in Fig. 7. The range of fruit lengths overlap although the means are significantly different between populations.

Hierarchical Grouping Analysis was used to determine if, on the basis of a number of characters, the individual specimens would form distinct, interpretable groups. Two different character sets were analysed using HGROU. These were the characters found to be significant in distinguishing populations using S.N.K., and the characters correlated to the factors produced by FACTOR.

The characters showing significant differences between populations (using S.N.K.), should be able to group the individuals into the original populations if the populations are well defined. The dendrogram resulting from using these characters in HGROU is shown in Fig. 8. Six significant groups were formed, and of these, only two conform to any of the populations sampled. Group 1 (Fig. 8) is composed mainly of individuals from the Goolwa-Strathalbyn (GS) population, Group 3 is composed of individuals from Victor Harbor (VH). Individuals from these populations are not confined to these groups. Other individuals from these populations are found in some of the remaining groups. Group 2 accounts for most of the individuals from the Tintinara-Culburra (TC) and Monarto (MM) populations. Individuals from other populations are common in this heterogeneous group. The Wyperfeld (WYP) and Pinnaroo-Bordertown 2 (PB2) populations are found mainly in Groups 4, 5 and 6. These groups are heterogeneous in composition. The populations Little Desert (LD) and Pinnaroo-Bordertown 1 and 3 (PB1, PB3) are spread evenly throughout Groups 2, 4, 5 and 6.

The groupings in Fig. 8 show the lack of definition of the populations, some of which (GS and VH) do have unique distinguishing characteristics. Although the groupings show strong differences between eastern and western samples, samples from some populations are split between the two major groups. This result can be interpreted as repeating the findings of the previous analyses, i.e. that there is a trend across the study area. The results from Differential Systematics are also repeated. Using differential systematics the VH, GS and MM populations have the highest rate of change between them and they are well separated by Hierarchical Groupings Analysis.

The characters accounting for the factors produced by Factor Analysis were also used for HGROU analysis. These characters were used to give an unbiased grouping of the individuals, the characters being uncorrelated. The groups of individuals produced by this analysis may represent a more natural grouping.

The population characteristics of the groups formed by this procedure are not as obvious as those from the S.N.K. characters. The western populations GS, VH and MM form a recognizable group (Group 6, Fig. 9) but this group includes several individuals from the east of the study area. The remaining groups (Groups 1-5, Fig 9) are heterogeneous.

The trends of groups and populations are not immediately obvious but it is possible to interpret the groupings from Fig. 9. They show that the populations from the western part are, in general, different from those in the eastern part, although considerable overlap



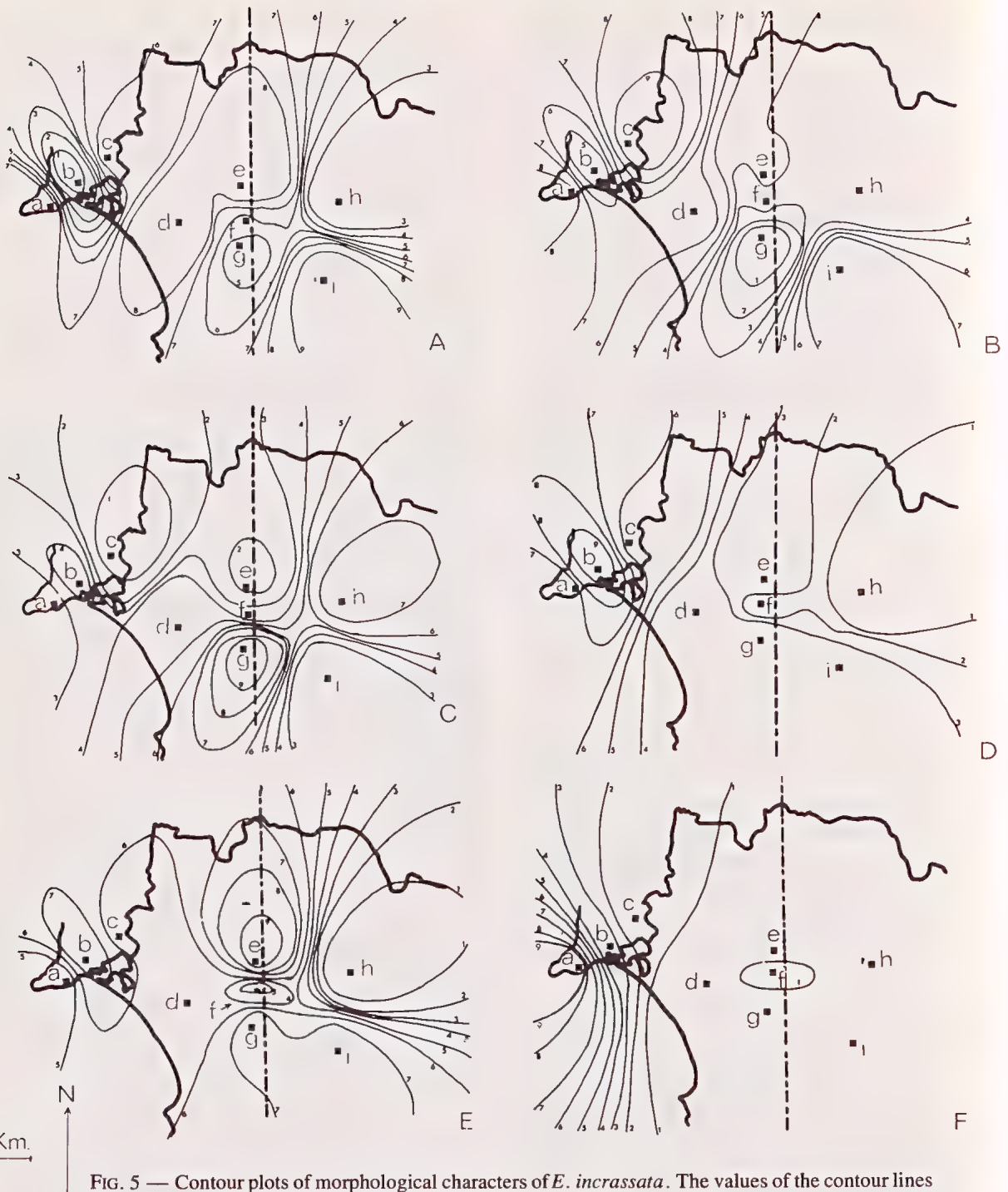


FIG. 5 — Contour plots of morphological characters of *E. incrassata*. The values of the contour lines represent ten divisions in the range of population means for each character. The smallest means have a contour value of less than one, the largest means a contour of greater than nine. A. Character LW; contour range 18.5-23.0. B. Character PL; contour range 14.0-19.0. C. Character L/P; contour range 4.8-6.3. D. Character FL; contour range 11.6-16.5. E. Character FW; contour range 9.4-11.8. F. Character PC; contour range 2.1-6.2. G. Character FLW; contour range 1.18-1.45. H. Character C/D; contour range 0.16-0.37. I. Character VN; contour range 3.04-3.28. J. Character FS; contour range 1.57-2.28. K. Character PD; contour range 13.3-17.80.

Population identity: a = VH, b = GS, c = MM, d = TC, e = PB1, f = PB2, g = PB3, h = WYP, i = LD.

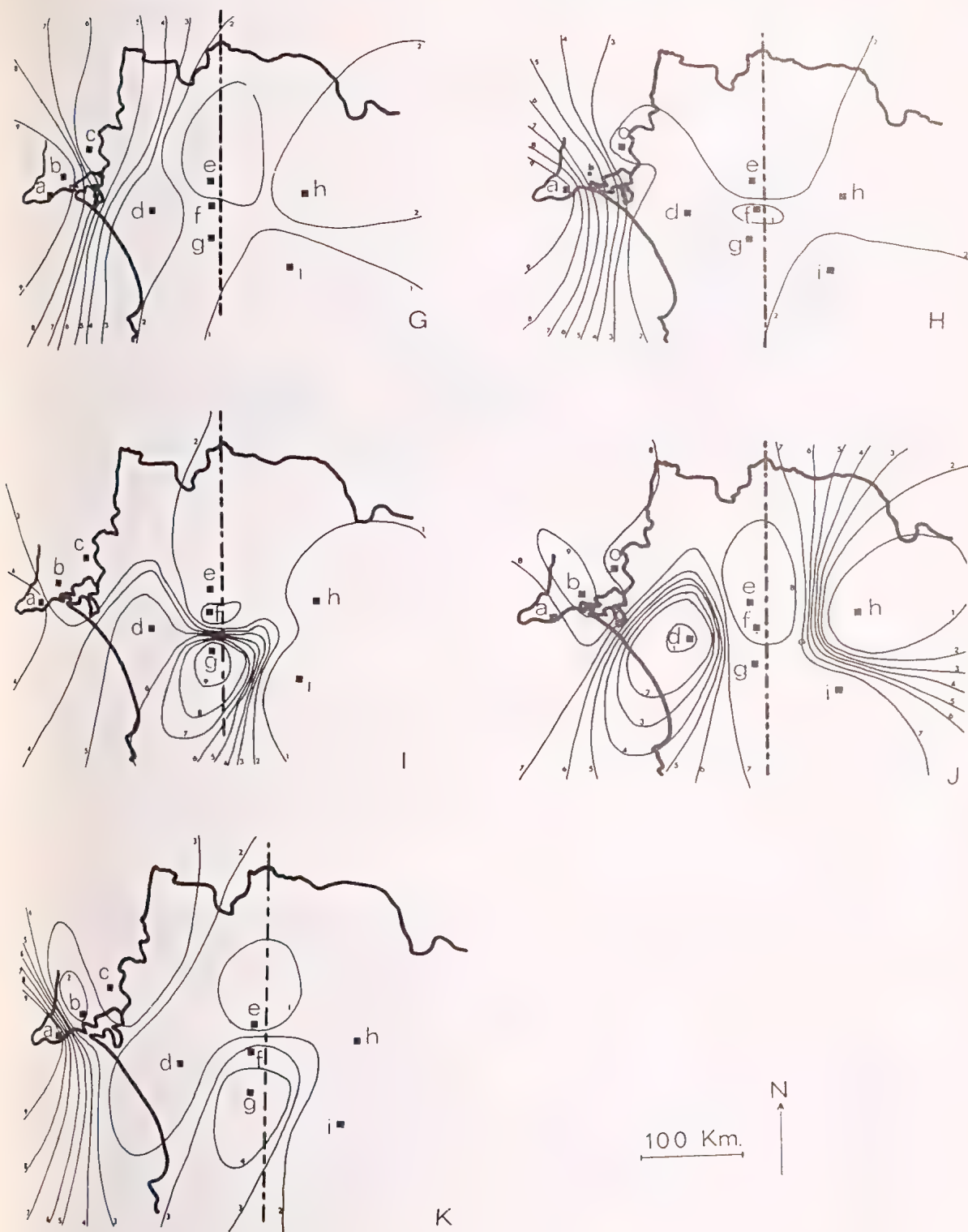


Fig. 5 (continued)



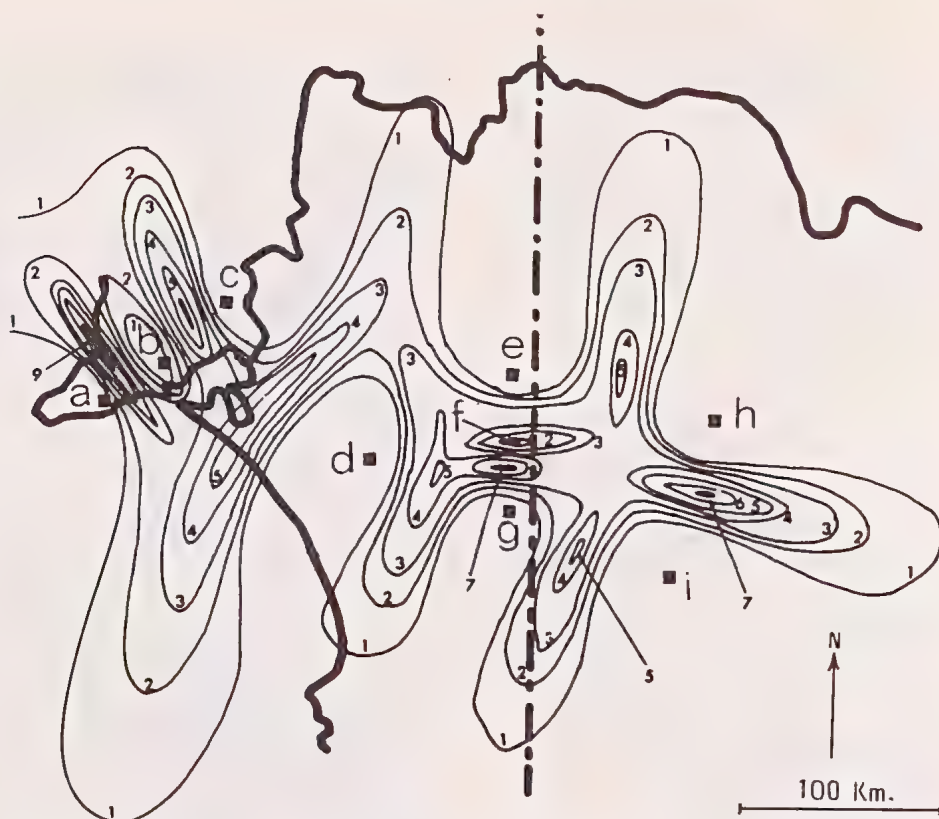


FIG. 6 — Contour plots for differential systematics of population means for all characters. The contour values are the average absolute differential of each of the characters. Population identities as for Fig. 5.

Contour values: 1 = 0.03, 2 = 0.05, 3 = 0.07, 4 = 0.09, 5 = 0.12, 6 = 0.14, 7 = 0.16, 8 = 0.18, 9 = 0.21

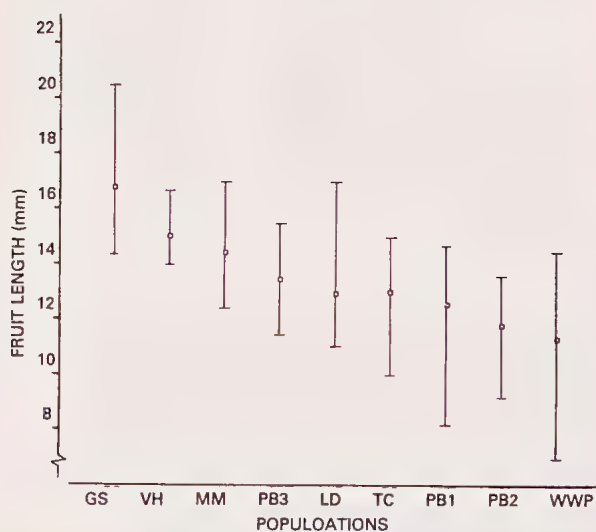


FIG. 7 — The mean (□) and range (I) of the fruit lengths found in the populations.

exists. The characters which account for the total variation produce groups which indicate a progressive gradient across the study area.

## DISCUSSION

*Eucalyptus incrassata* shows morphological variation without discontinuities across the study area. There is no evidence to suggest that the varieties *angulosa*, *costata* and *incrassata* are sufficiently distinct in terms of morphology and distribution to be regarded as separate species. The morphological changes observed can be explained as a cline extending from var. *angulosa* in the west to var. *incrassata* in the east. The clinal variation observed appears to be correlated to the amount of water available to the trees (Fig. 2 and Appendix). Pryor (1976) has stated that clines of continentality are found in eucalypts extending inland from the coast and that these are often correlated with increasing aridity. The inland forms of such a cline

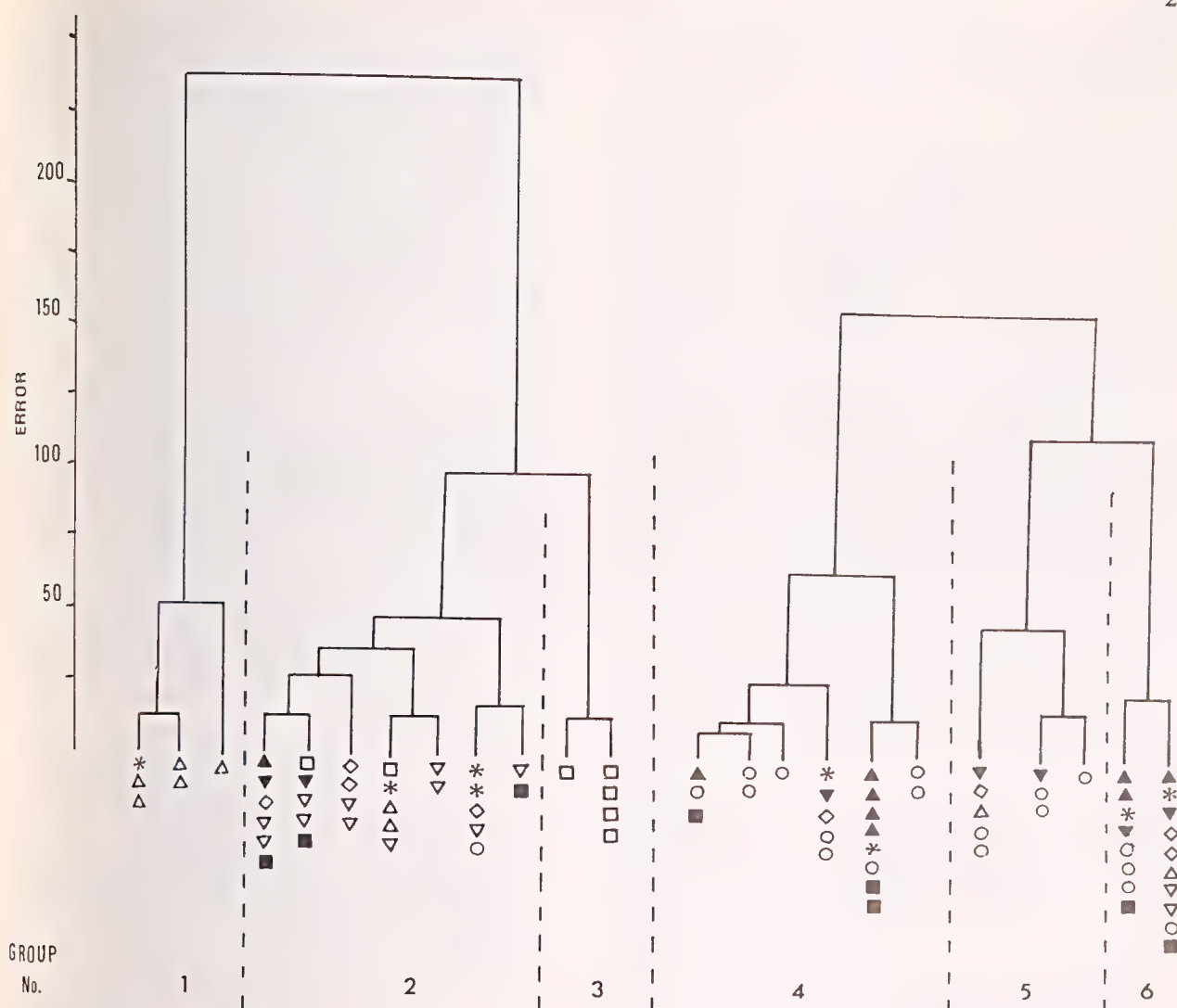


FIG. 8 — Hierarchical grouping of specimens collected using those characters which separate the populations.

Key to populations:  
 □ = VH, △ = GS, ▽ = MM, ◇ = TC,  
 ▲ = PB(1), ■ = PB(2), ▼ = PB(3)  
 ○ = WYP, \* = LD

possess smaller organs (fruit and leaves) than the coastal forms. The cline of *E. incrassata* appears to be of this type.

Chippendale (1973) records var. *angulosa* in the very arid Nullarbor-Roe Plain region. This suggests that factors other than rainfall may be responsible for the variation of the species. The distributions given by Chippendale (1973) for var. *angulosa* and var. *incrassata* support the notion that a cline of continentality exists: the cline appears to be correlated to a sea/land gradient. Distance from the coast is the only common factor readily observable which explains the apparent variation pattern.

A continuous series of morphological forms was found in samples from nine arbitrarily selected sites in the 60,000 km<sup>2</sup> study area. The absence of discontinuities between the morphological extremes of *E. incrassata* (i.e. var. *incrassata* and var. *angulosa*) is good evidence for the incorporation of the taxa, var. *incrassata*, var. *costata* and var. *angulosa*, in one species. The correct name for this species is *E. incrassata* Labill. which has priority over *E. angulosa* Schauer and *E. costata* Behr. et Muell. ex Miquel.

Clinical variation presents problems with the nomenclature of the species involved. One of the prerequisites of a satisfactory classification scheme is its



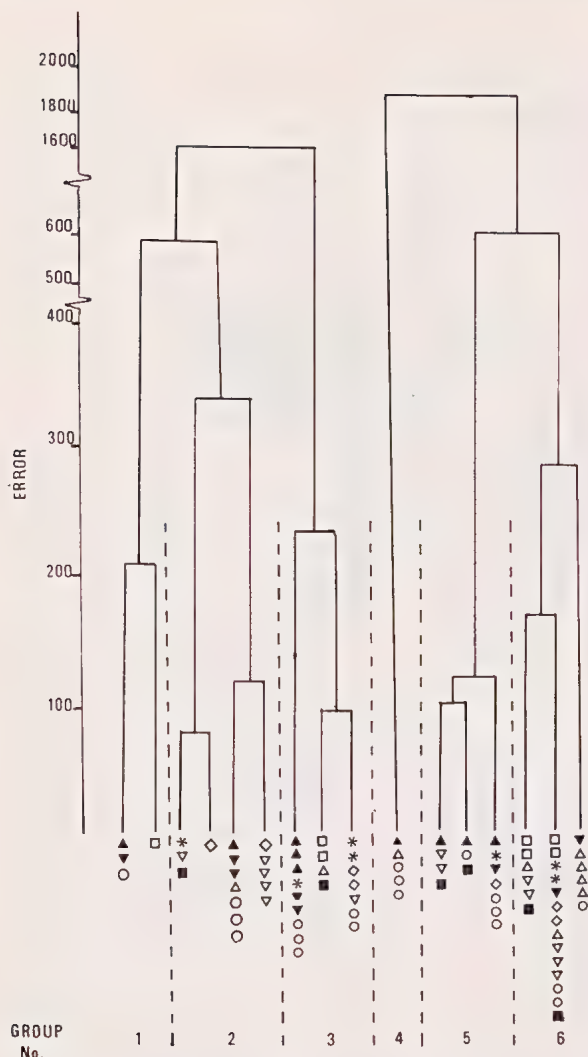


FIG. 9 — Hierarchical grouping of specimens collected using those characters correlated to factors.

Key to populations:

□ = VH, △ = GS, ▽ = MM, ◇ = TC,  
 ▲ = PB(1), ■ = PB(2), ▼ = PB(3)  
 ○ = WYP, \* = LD

ability to permit accurate identification of the species of individual samples and to account for differences in morphology. Chippendale (1973, 1976) regards the taxon *E. angulosa* to be a valid species (Chippendale 1977 pers. comm.). The term species implies that the taxa are distinct entities (Davis & Heywood 1963). Pryor (1956) proposed that the term 'cline-form' be used to identify reference points within a cline, but this term has not been generally accepted (Pryor & Johnson 1971). The most satisfactory means of describing a cline in terms of nomenclature is to establish a series of infra-specific categories which provide reference

points for the cline. Sub-species are major morphological subdivisions of the species, while the term variety implies a localized, morphologically distinct group within a species (Davis & Heywood 1963). The term 'sub-species' is preferable to 'variety' for naming 'cline-forms' as it implies that populations, rather than scattered individuals are being classified (Pryor & Johnson 1971).

The classifications of *E. incrassata* vary in the infra-specific epithets used. In explaining the cline observed, the most useful classification is that of Burbidge (1947) in which three varieties exist: *E. incrassata* Labill. *sensu stricto*, *E. incrassata* var. *costata* Burbidge, *E. incrassata* var. *angulosa* Benth. This classification is a reference to the end points, as well as to the centre of the range, and such a classification is necessary to describe clines (Jackson 1960). To clarify the meaning of *E. incrassata* Labill. *sensu stricto* Boomsma (1969) proposed the epithet *E. incrassata* var. *incrassata*.

The appropriate nomenclature for the *E. incrassata* group should be based on that of Burbidge but substituting the term sub-species for variety. The use of Boomsma's infra-specific epithet *incrassata* in place of *sensu stricto* provides a more suitable combination. The proposed nomenclature is as follows.

#### *Eucalyptus incrassata* Labill., 1804

##### (a) *Eucalyptus incrassata incrassata*

The type specimen for the species is located in the Florence Herbarium, Italy. Boomsma (1969) has examined photographs of the specimen. The type is apparently a good example of the taxon.

*Distinctive features of taxon:* mature fruit 7-12 mm long x 6-10 mm diam.; fruit surface smooth to striate. This taxon can be applied to the populations WYP, PB(1), PB(2), and TC.

##### (b) *Eucalyptus incrassata costata* (Behr. et Muell. ex Miquel) Johnstone et Hallam. Stat. nov.

*Eucalyptus costata* Behr. et Muell. ex Miquel, 1859

*Distinctive features of taxon:* mature fruit 11-17 mm long x 10-13 mm diam.; fruit surface costate. This taxon can be applied to the populations MM, LD and PB(3).

##### (c) *Eucalyptus incrassata angulosa* (Schauer) Johnstone et Hallam. Stat. nov.

*Eucalyptus angulosa* Schauer 1843

*Distinctive features of taxon:* mature fruit 14-23 mm long x 10-14 mm diam.; fruit surface costate to angular. This taxon can be applied to the populations VH and GS.

The purpose of proposing three infra-specific taxa is to facilitate accurate identification of *E. incrassata*.

sata specimens. Not all specimens will fit easily into a taxon. The continuous series of forms means that intermediates between the taxa will occur. Such cases can be determined with care or left as 'intermediate'

Previous authors (Chippendale 1973, Burbidge 1947) have distinguished the taxa mainly on the basis of ribbing of the fruit surface. The strong correlation between fruit size and surface ribbing gives a more readily quantifiable character for identification, such that the infra-specific taxa can be identified by using a combination of these characters.

## CONCLUSION

*E. incrassata* shows a cline of continentality extending in an easterly direction inland from the coast in the region of the Murray River mouth. This cline encompasses the taxa *E. angulosa*, *E. costata* and *E. incrassata*. In view of this apparent clinal variation three infra-specific taxa have been proposed; these provide reference points within the cline as an aid to the identification of *E. incrassata* individuals.

## ACKNOWLEDGMENTS

We are indebted to Dr. D. M. Simmons for helpful discussion on the use of computer programs and to the National Parks and Wildlife Service of Victoria for enabling collections to be made in Wyperfeld and Little Desert National Parks.

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## APPENDIX 1

## LOCATION OF COLLECTION SITES

Population Code	Location	Rainfall* (cm/yr)			
WYP	Wyperfeld National Park north-west Victoria [Ring Road, Brambruk Track & Dattuck Track (western 4 miles)].	33	VH	2 miles west of Victor Harbor, on coast road to Cape Jervis.	51
LD	Little Desert National Park western Victoria (site nr. former Kiata Lowan Fowl Sanctuary).	38	MM	Northern side of Dukes Highway, 1.5 miles west of Murray Bridge.	46
TC	South side of Dukes Highway, 1 mile east of Culburra.	46	PB1	Eastern side of Pinnaroo-Bordertown Road, 11 miles south of Murray Bridge turn-off.	41
GS	Western side of the main Goolwa-Strathalbyn Road, 15 miles north of Goolwa.	48	PB2	Parking Bay, eastern side of Pinnaroo-Bordertown Road, 32 miles south of Murray Bridge turn-off.	44
			PB3	Pinnaroo-Bordertown Road, at turn-off to Keith, 15 miles north of Dukes Highway.	46

\*Average annual rainfall recorded at nearest rainfall station.

MM, PB1, PB2 and PB3 determined by interpolation.

## FORAMINIFERAL DISTRIBUTION IN THE ESTUARINE GIPPSLAND LAKES SYSTEM, VICTORIA

By M. APHORPE\*

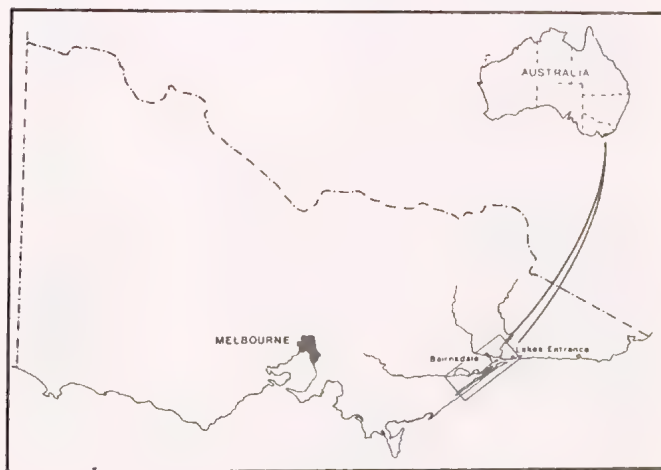
**ABSTRACT:** The estuarine system known as the Gippsland Lakes extends over 75 km along the coastal plain of eastern Victoria. A complete range of water salinities from almost fresh to marine is developed in the system. Variation in salinity appears to be the principal factor controlling the distribution of the eleven separate foraminiferal faunas developed in the bottom sediments. At the seaward end of the system a semi-marine, calcareous fauna is developed. Three separate central faunas occupy waters of intermediate salinity. Faunas at the landward extremes of the system are composed mainly of arenaceous foraminifera tolerant of very low salinities. Peripheral lagoons and channels contain variants of all these faunas, or occasionally distinctive assemblages of their own. Each assemblage is briefly described and an attempt is made to indicate controlling environmental factors. The pH of the substrate is also believed to be important in determining the major groups of foraminifera present. Below 6.5 only arenaceous types are present, while above 8.5 virtually only calcareous species occur. Between approximately 6.5 and 8.0, the two groups are mixed.

### INTRODUCTION

The large estuarine system known as the Gippsland Lakes lies along the southeast coast of Victoria. The lakes are a string of connected shallow lagoons running subparallel to the coastline with Bass Strait, from which they are separated by a narrow dune ridge system, and swampy low sandy plains of variable width. The artificially dredged sea entrance, cut late in the nineteenth century, and just west of Lakes Entrance, maintains the estuarine character of these water bodies. Without this dredged channel, the lakes would return to a dominantly lacustrine system, with perhaps only occasional marine influence caused by storm breakthroughs in the dune barrier.

The lakes fill shallow depressions in an older coastal plain (Fig. 1) (see Bird 1965 for a detailed geomorphological study). They extend over a length of 75 km along the coastal plain. At its widest point the lakes system is approximately 16.6 km across, but has an average width of 5 to 8 km. It covers an area of approximately 280 km<sup>2</sup> but is generally less than 9 m in depth. The pronounced linear shape, as well as a subdivision into several lake basins with narrow connections, has the important effect of raising the number of discrete faunal associations occurring in a relatively small area. Freshwater influx into the lakes is provided by five major rivers (Fig. 1). Cool rainy winters produce a high stream discharge which lowers the salinity of the whole system in winter and spring. Warm dry

summers generally mean that water loss by evaporation is largely replaced by seawater. During this period the entire lakes system is influenced by tides. The variation in water level is about 0.6 m at the seaward end, and appears to be somewhat less at the landward end in Lake Wellington. Although the salinity values change in response to the factors described above, at all times during the year, there is a salinity gradient. In water depths greater than about 1.6 m, there is a pronounced vertical salinity difference between bottom and surface water, due to the presence of a bottom wedge of denser more saline water. Because of their



INDEX MAP

\*Woodside Petroleum Development Pty. Ltd., Box D 188, G.P.O. Perth, Western Australia, 6001.



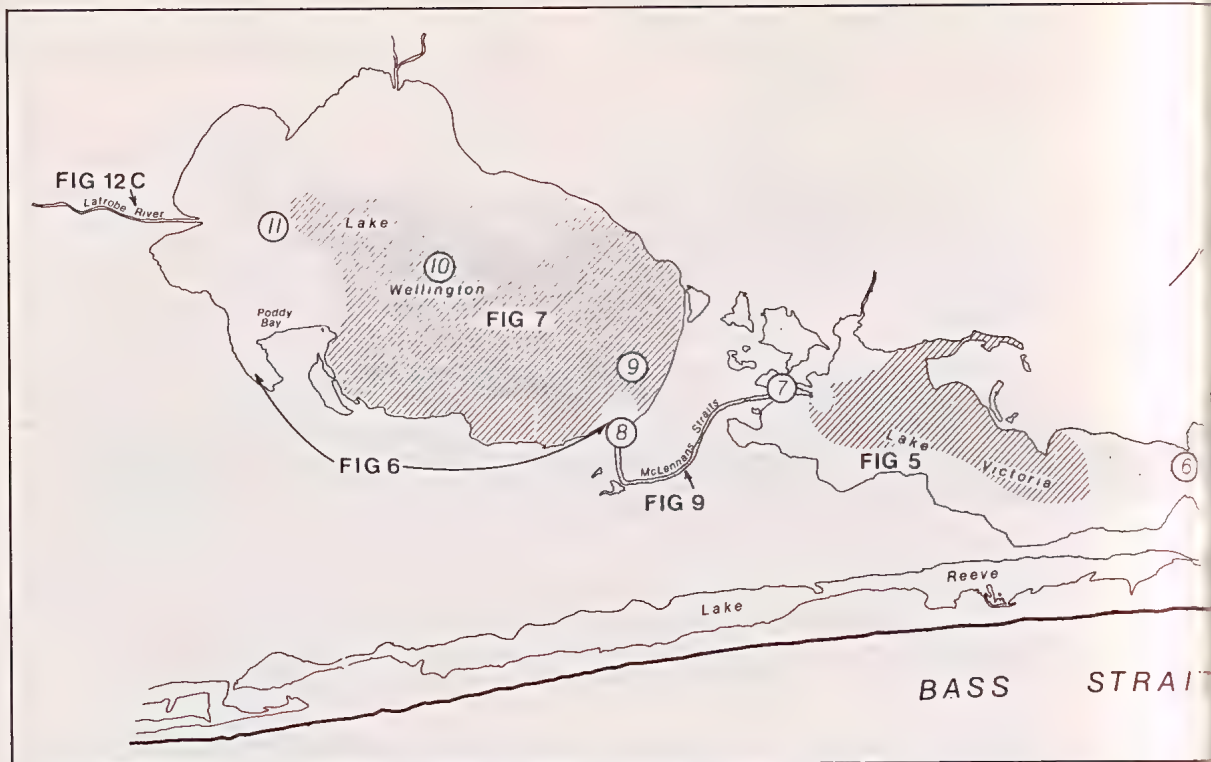


FIG. 1 — Key Map to Gippsland Lakes System, with index to faunas. Locations of sub- detailed Figs. (2-12) are marked. These give details of different Faunas described

benthonic habitats, the foraminifera are influenced by the more saline bottom water.

The central parts of all lakes are floored by clay or silty clay, often with a dense growth of vegetation. The colour of the clay varies from black in Lake Victoria to reddish tan in Lake Wellington. The margins of the lakes, and narrow waterways scoured by tidal currents, have medium to coarse-grained shelly sand bottoms. Shallow banks have patchy vegetation on a sand floor. Those areas of shallow protected lagoons less than a few metres deep are thickly carpeted with a filamentous algal growth.

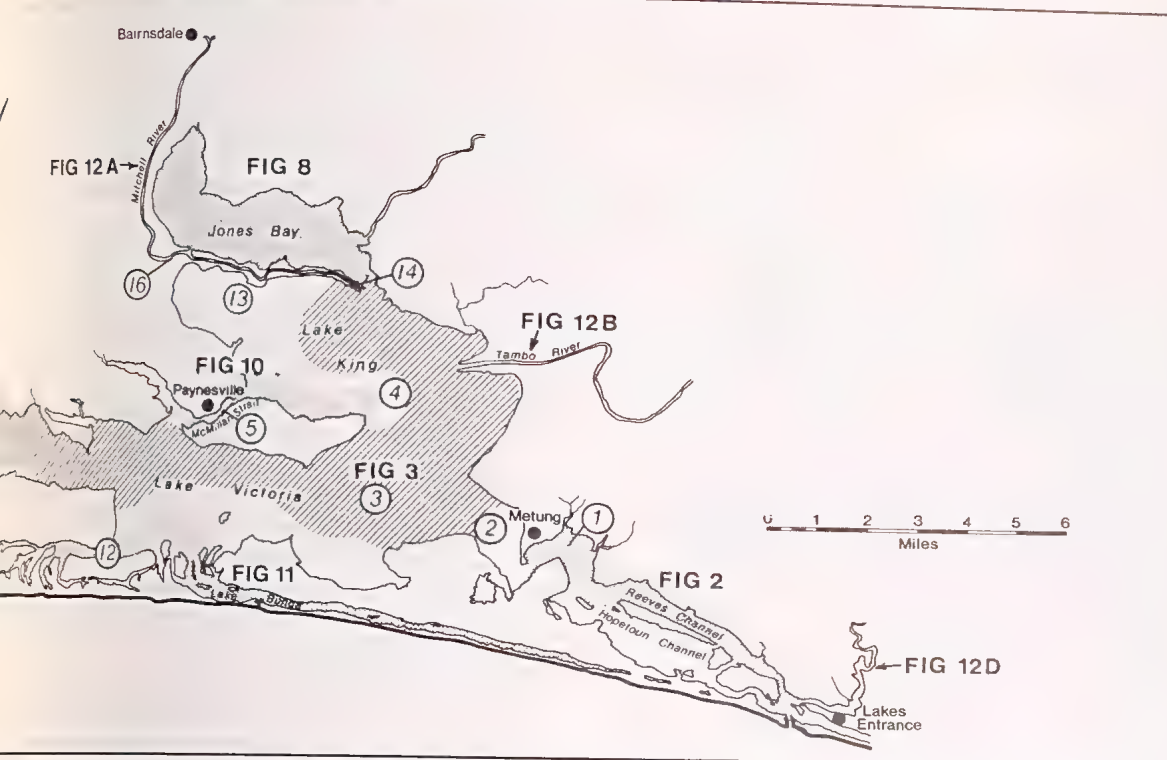
Variations in substrate are caused by varying energy conditions. These are the result of 2 factors: (1) tidal currents, which move through narrow connecting channels with considerable velocity (enough to erode and transport silt-sized sediment), (2) waves, of up to 0.6 m high, caused by frequent and prolonged winds blowing parallel or subparallel to the long axis of the lakes system. This wave action is sufficient to sort sediment and produce a sandy sediment rim around the margins of most lakes. Shallow clay-floored lakes such as Wellington and Jones Bay appear to have part of their clay sediment in constant suspension. This constant turbidity of the water is tolerated by one species, *Martinotiella* cf. *communis*, which is most abundant in

such areas. Different faunas are observed on sandy and muddy-floored portions of the same lake, where other environmental parameters appear to be similar.

The effect of pH values in bottom sediment on foraminiferal distribution was briefly examined and it appeared to be important in determining the major groups present.

## PREVIOUS WORK AND BACKGROUND TO THE STUDY

The Victorian Ministry for Conservation has recently begun an intensive study of the Gippsland Lakes system, but at the time of this study, the only published work on the Lakes as an entity was that by Bird (1965). The present survey, the first on the foraminifera of the Gippsland Lakes, began as a modest private collection of samples taken for casual interest and without any overall study in view. The foraminiferal faunas of the early samples, when discussed with D. J. Taylor, were thought to be sufficiently interesting to continue the collection of material. The aim of the survey has been to determine the qualitative and quantitative compositions of the foraminiferal faunas, and to suggest, if possible, some reasons for the distribution patterns of different taxa



Encircled numerals 1-16 indicate Water Sampling Stations of Victorian State Rivers Water Supply Commission.

and faunas. It is hoped that such a survey will provide a starting point for more detailed investigations.

The only local foraminiferal study with which the Gippsland results could be compared was that by Collins (1974) on the foraminifera of Port Phillip Bay at Melbourne. Port Phillip is a single body of water, very much larger than the Gippsland Lakes, and is overall of more marine character. Collins's study was of the nature of a faunal inventory. An examination of Collins's material in the collection of the National Museum of Victoria showed little, if any, similarity between the assemblages of the two areas.

#### SAMPLING EQUIPMENT AND METHODS

Sampling was carried out over a four-year period from 1970 to 1973, usually late December to early January, and in April, when circumstances permitted. Samples were collected using a simple dredge dragged behind a boat. It collected sediment to a depth of 3 cm over a linear path of about twenty m. Water samples were collected using a heavily weighted bottle, or were taken direct from the sediment water mixture in the dredge in shallow water areas. Water salinity measurements were carried out by the Victorian Department of Minerals and Energy, Chemical Branch. The monthly salinity readings taken by the

Victorian State Rivers and Water Supply Commission (hereafter referred to as "State Rivers") at 16 stations were also utilized for those months in which samples were collected. Readings for pH were taken using indicator papers made by the British Drug Houses Company. Some readings were confirmed by Department of Minerals and Energy measurements.

In the laboratory, a 20g sample of sediment was washed free of clay-sized particles, dried, and floated in carbon tetrachloride to separate the foraminifera. The foraminifera in all 366 samples collected were then identified and counted. Because of the method of collection and the consequent mixing of surface and subsurface material, it was impossible to separate foraminifera living on top of the sediment from those living or dead within the top layers of sediment. Selective staining of some samples with Rose Bengal to identify live specimens showed that the living species did not differ greatly in composition from the dead specimens in the same samples. Because of this it is considered that the total fauna present in each sample gives a fair representation of the living population at each site. Post-mortem transportation of specimens, with the exception of tidal channels, is believed to be minimal.

A collection of foraminiferal preparations,



consisting of part or all of the foraminifera recovered from each 20g sample, are stored in the Department of Invertebrates, National Museum of Victoria, Melbourne. A list of sample locations is lodged with the samples.

The discussion of the foraminiferal faunas encompasses all the samples examined, but only selected 'typical' samples have been shown in graphical form on the Figures. Distribution tables, either in abbreviated form showing selected samples only, or in complete form giving all samples and all species identified, are available on request from either the author or the Royal Society of Victoria.

## FORAMINIFERAL ASSEMBLAGES

At least eleven benthonic faunal assemblages have been distinguished in the lakes during this survey. Because of the small number of species and the constant character of most assemblages, simple 'pie diagrams' have been used on Figs. 2-12 to illustrate the foraminiferal distribution. The faunas are fairly distinct, with little overlap at any one time, but resampling of some sites indicates that the faunal assemblages may migrate in response to varying environmental conditions. Some samples may represent mixing of two distinct faunal assemblages which were deposited in very thin layers in the lake sediments.

In common with hyposaline lagoons and estuaries in other parts of the world the foraminifera belong almost entirely to two suborders, *Textulariina* and *Rotaliina* (Murray 1973). The third suborder, the *Miliolina*, occurs only in the semi-marine entrance to the lakes system. Also in common with other lagoonal and estuarine systems, the species diversity is generally low in the lake faunas, and fairly high in the marine-influenced entrance fauna.

Planktonic foraminiferal species are virtually absent. In Fauna 1 (nearest the sea) five samples contain 1.5% planktonic species, but none at all were found in other faunas.

The faunal assemblages are listed below. For Fauna 1-8 the principal distinguishing forms are given.

*Marine Faunas*, Bass Strait.

*Fauna 1* — Semi-Marine Fauna: with Miliolids.

*Fauna 2* — Central Lakes Fauna: *Ammonia*/*Eggerella*.

*Fauna 3* — Central Lakes Fauna: *Ammonia*/*Eggerella*/*Nonion*.

*Fauna 4* — Southern Lake Victoria Fauna: *Ammonia*/*Elphidium oceanensis*.

*Fauna 5A* — Inner Lakes: arenaceous: *Trochammina*.

*Fauna 5B* — Inner Lakes: mixed arenaceous/calcareous: *Martinotiella*/*Miliammina*/*Ammonia*.

*Fauna 5C* — Inner Lakes: mainly arenaceous: *Martinotiella*/*Miliammina*/*Ammobaculites*/*Ammonia*.

*Fauna 6A* — High Energy Channels — McLennans Strait: *Ammonia*/*Ammotium*.

*Fauna 6B* — High Energy Channels — McMillan Strait: *Eggerella*/*Ammobaculites*/*Miliammina*.

*Fauna 7A* — Low Energy Environments — Lake Bunga: *Ammobaculites*.

*Fauna 7B* — Low Energy Environments — Lake Bunga: *Elphidium*.

*Fauna 7C* — Low Energy Environments — Lake Reeve: *Elphidium articulatum*/*Ammonia*.

*Fauna 8* — River Faunas.

The *Marine Faunas* of Bass Strait were sampled at only three stations immediately outside the entrance to the lakes. Sparse faunas were found in sands of the turbulent nearshore zone. They are not discussed here, as an analysis of them is beyond the scope of this paper. The major assemblages of the Gippsland Lakes system are as follows:

### *Fauna 1* — SEMI-MARINE FAUNA

This occurs in the deep Reeves Channel connecting the main lakes with the sea at Lakes Entrance. The relatively straight channel runs for 10 km along the base of the Pleistocene coastal escarpment from Metung to Lakes Entrance (see Fig. 2). The channel is about 400 m wide for most of its length, 10-12 m deep in the centre, carries most of the water exchanged between lakes and ocean and has the highest current velocity (tidally induced) of any part of the lakes system under normal (i.e. nonflood) conditions. Sediment samples recovered in the channel are of silt or silty sand. Related faunas occur in the shallow Hopetoun Channel to the south, but these will be discussed separately.

The principal feature which distinguishes this foraminiferal fauna from all others in the lakes is the presence of miliolids. This group is predominant in many shallow water marine environments, including the immediately adjacent area of Bass Strait. At the seaward end of Fauna 1, the miliolids form over half the total population. The second feature which distinguishes this fauna is the high species diversity of over 20 species per sample with the maximum number recorded being 58 in sample GL 145. High diversity is one feature which distinguishes marine assemblages from lacustrine or marginal marine assemblages. Abundance is variable, depending on the nature of the sediment. Sandy samples contain under 100 specimens, whereas finer grained samples contain thousands per 20g of sediment.

Approximately 10 different species of miliolid foraminifera are present, the most common being



*Quinqueloculina seminulum*, *Q. tropicalis*, *Miliolinella subrotunda* and *Triloculina trigonula*. Species belonging to the Family *Elphidiidae* are common in all samples. *Elphidium macellum* is important in the north-east half of the area of Fauna 1, while *E. advena*, *E. articulatum* and *Criboelphidium poeyanum* are more common with increasing distance from the sea. Moving up Reeves Channel towards the lakes, *Ammonia aoteanus* becomes the dominant species, forming 30% to 70% of the total population in the inland half of this fauna. Calcareous foraminifera are completely dominant over arenaceous types. The genus *Cibicides*, which is abundant or dominant in many shallow marine shelf assemblages, is almost completely absent from this fauna. Among the minor species present *Textularia pseudogramen* is a species living on the Gippsland continental shelf which is found only in the seaward end of Fauna 1. *Eggerella advena*, which is characteristic of Lake Victoria faunas, occurs in abundance in some samples towards the lakesward end of Fauna 1. *Trochammina rotaliformis* seems to occur only in samples where tidal currents sweep around promontaries or through narrow channels. This species is prominent in sample 204 (in Rigby Strait, discussed later); in sample 242 between Pelican Island and Barwon Point; in sample 5 (strictly in Fauna 2) where strong currents pass the shore at Metung; and it occurs in small numbers in central Reeves Channel. *Fursenkoina fusiformis* and *Nonion depressulum* occur in very small numbers in the lake-ward part of the area of Fauna 1. Another 60 species occur in very small numbers scattered along the length of the Reeves Channel without apparent pattern. These include *Ammobaculites barwonensis*, *Haplophragmoides canariensis*, *Martinotiella cf. communis*, *Miliammina fusca*, *Reophax barwonensis*, *Trochammina inflata*, *Quinqueloculina cf. ferrusacci*, *Q. striata*, *Triloculina tricarinata*, *Angulogerina angulosa*, *Anomalina glabrata*, *Astrononion tasmanien-sis*, *Bolivina pseudoplicata*, *B. striatula*, *B. variabilis*, *Bolivinella folium*, *Bulimina gibba*, *B. marginata*, *Buliminella elegantissima*, *Cassidulina cf. neo-carinata*, *C. subglobosa*, *Cibicides refulgens*, *C. mediocris*, *Conorboides advena*, *Discorbinella sub-bertheloti*, *Discorbis* spp., *Euuvigerina peregrina*, *Fissurina annectens*, *Guttulina problema*, *G. regina*, *Lagena* spp., *Lenticulina* spp., *Patellinella inconspicua*, *Pileolina patelliformis* and *Planodiscorbis rarensens*. A small number of planktonic specimens, mainly juveniles, occur in most samples.

This fauna occurs in salinities of 30 to 35‰. Readings at State Rivers Station No. 1, in Reeves Channel east of Metung were somewhat lower, ranging from 26 to 30.4‰. For months in which samples were taken, the readings for this station were:

	Salinity (‰)
January 1970	28.7
March 1970	26.6
January 1971	25.9
April 1971	30.0
April 1972	30.4
June 1972	27.18
December 1972	28.4
April 1973	29.58

Water sample 138 (collected at the end of December 1970) near the seaward end of the area had a salinity of 35.4‰. Two samples (144, 145) taken immediately afterwards 7 km further inland along the channel, where *Ammonia* was the most abundant foraminiferid, had water salinities of 25.8 and 30.1‰. The difference in these last two adjacent samples reflects the presence of a wedge of denser, more saline water at depth, overlain by a lighter less saline surface layer. In June 1972 a water sample (no. 280) at the same location as sample 243 gave a salinity of 30.5‰.

The semi-marine Fauna 1 does not occur in a second broad channel to the southeast (the Hopetoun Channel) which also connects the main lakes and the sea (see Fig. 2). Although wide, most of the area is extremely shallow and covered with dense weed beds. A central channel, some 2 to 2.7 m deep, winds to the sea entrance and is floored with mixtures of sand, silt and clay. Water flow through this shallow channel system appears to be only a fraction of that in Reeves Channel. Samples from this area have salinity values of 26, 29 (two samples) and 31‰. The proximity of this area to Reeves Channel invites comparison of the faunas. In the Hopetoun Channel, faunas are very variable. The nature of the substrate appears to be an important control here. The faunas in the sandy channels are dominated by *Ammonia aoteanus* with fewer *Elphidium* spp. and other species. Miliolids are absent (with the exception of a single sample — 252). The number of species per sample is lower than in Reeves Channel faunas.







Two samples (246, 247) were taken in Yellow Bay, a protected backwater at the southwestern end of the Hopetoun Channel. The water depth here is 4 m, but 2 m of this is occupied by a dense growth of filamentous algae. Sample 246 from a small patch of black silty clay within the weed beds produced abundant molluscs and a foraminiferal assemblage dominated by *Ammobaculites barwonensis* (63%), with *Ammonia aoteanus* (27%) and *Elphidium articulatum* (3.8%). Sample 247 was barren. The weed bed fauna of sample 131, taken in the main channel off Kelly Head in less than 2 m of water, was entirely different, consisting largely of algae with only a few grams of



## LEGEND

- 123• Sample No. with location well defined  
 (67) Sample No. with location vague  
 NF No foraminifera found  
 ANF Almost no foraminifera found  
 --- Approximate limits of fauna






### TEXTULARIINA

-  *Ammobaculites barwonensis*  
 *Ammotium salsum*  
 *Eggerella advena*  
 *Martinotiella communis*  
 *Miliammina fusca*  
 R *Reophax barwonensis*  
 ○ ○ *Trochammina rotaliformis*  
 *Trochamminita irregularis*



### MILIOLINA

### ROTALIINA

-  *Ammonia aoteanus*  
 *Criboelphidium poeyanum*  
 *Elphidium articulatum*  
 E *Elphidium macellum*  
 *Elphidium oceanensis*  
 *Nonion depressulum*

TO BE USED IN CONJUNCTION WITH FIGS. 2-12.

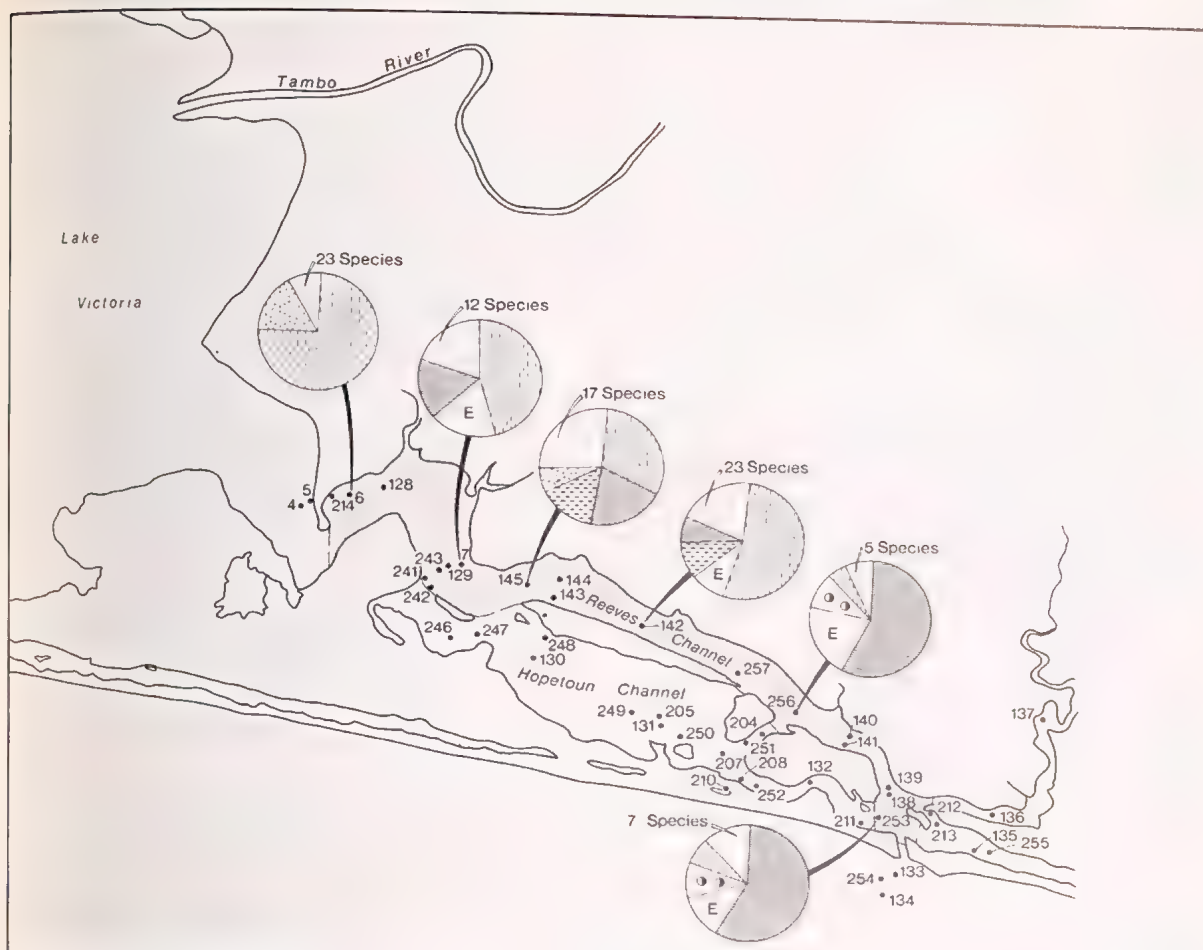


FIG. 2 — Fauna 1: Semi-marine Fauna.

black clay adhering to the plants. Very abundant small gastropods and ostracods, all living, were recovered from the algal fronds. Abundant living *Miliammina fusca* made up 95% of the foraminiferal assemblage, and it is believed that most of the specimens were recovered from the algae rather than from the clay of the substrate. Both these faunas suggest that arenaceous species predominate in weed-covered areas of the lakes regardless of salinity and other factors.

Another faunal variant in this area is the high percentage of *Trochammina rotaliformis* in the sparse faunas on shallow sand banks (sample 248: 77%; sample 250: 76% *T. rotaliformis*). The species is less common in the faunas of channels in this area (sample 130: 10%, sample 204: 6%; sample 251: 4.5%). In summary, on the sand banks *T. rotaliformis* is dominant, with minor *Ammonia aoteanus* and *Miliammina fusca*, whereas in the channel faunas *Trochammina rotaliformis* is overshadowed by *Ammonia aoteanus* and *Elphidium articulatum*.

Four samples were taken in the Cunninghame Arm, east of Lakes Entrance township. The sparse

faunas in samples 135, 212, 213 and 255 are very similar to those of the Hopetoun Channel. *Ammonia aoteanus* is the most common species, with minor numbers of *Elphidium articulatum*, *Elphidium macellum* and *Criboelphidium poeyanum*. Numerous other species occur in extremely small numbers.

#### Fauna 2 — CENTRAL LAKES FAUNA

Lake Victoria and its western extension, Lake King, are the principal water bodies of the Gippsland Lakes, being 38 km long, and 7-10 m deep over much of their area. Fauna 2 occupies the seaward parts of these lakes and is one of the most extensive faunas in the lake system (see Fig. 3). It appears to be partially controlled by substrate, having been found only in clay or very fine silt in the central, deeper parts of the lakes.

Fauna 2 is composed almost entirely of only two species — *Ammonia aoteanus* and *Eggerella advena* in roughly equal numbers. It has the lowest diversity and greatest abundance of any fauna, which is surprising considering its proximity to the entrance to the lakes. Four of the samples collected in 1970 had



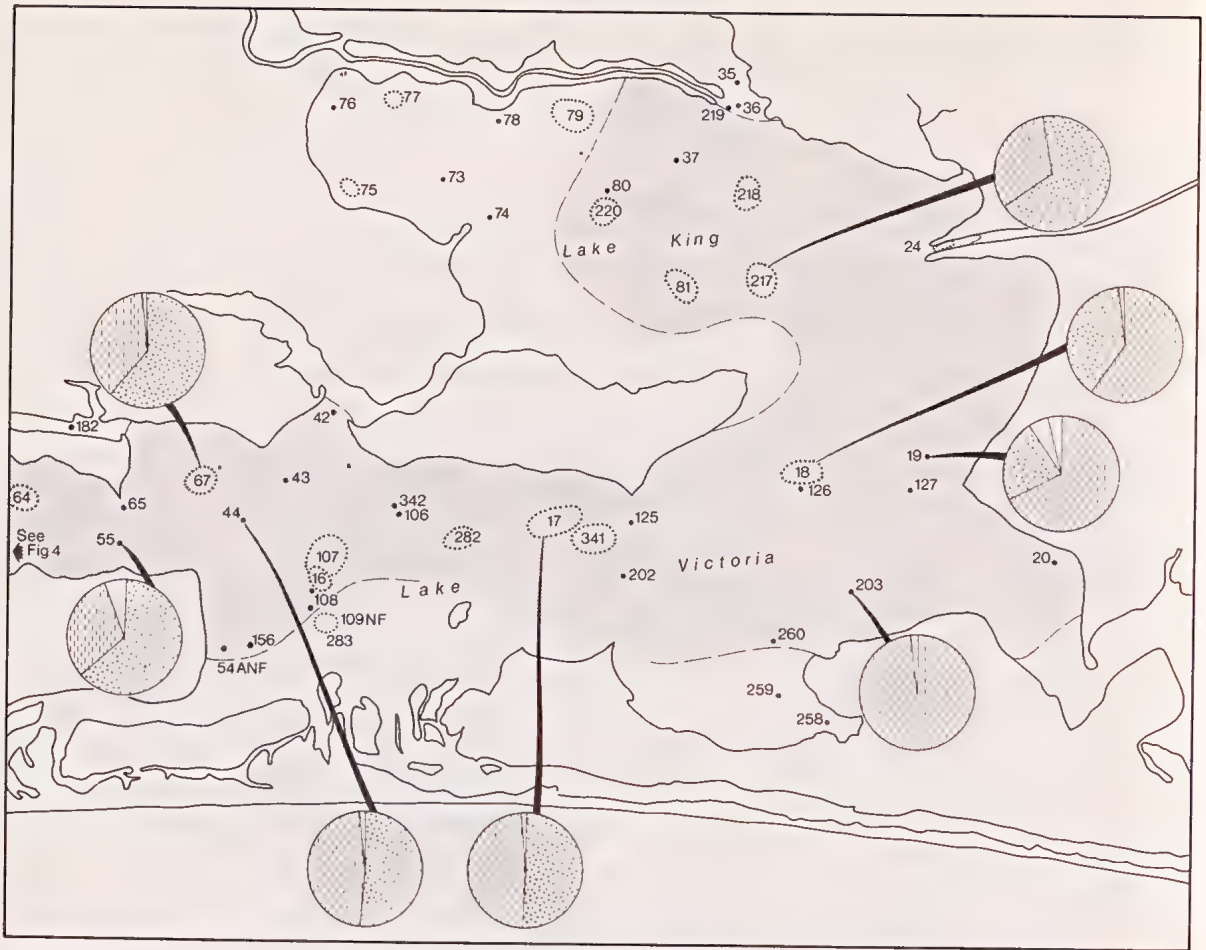


FIG. 3 — Fauna 2: Central Lakes Fauna (*Ammonia*/*Eggerella*).

over 10,000 specimens per 20g of sediment. Later samples did not approach these numbers, but most had over 1,000 specimens per 20g. Only two pH readings (of 7.0 and 7.5) were taken in Lake King during sampling.

Water salinity values were mostly in the range of 26 to 31‰. However, considerably lower salinity measurements, of 12, 15 and 20‰, were obtained in this area at different times during 1970. The samples associated with the readings of 12 and 20‰ were almost totally lacking in foraminifera. The samples of 15‰ had very high population numbers, so that no coherent picture emerges on the salinity range for this fauna. In general, *Eggerella advena* comprises more than half the population in the lower salinity samples from the inland part of this fauna (samples 217, 17, 107, 43, 44, 67, 55, 64). *Ammonia aoteanus* forms more than half the population in the more seaward samples of this fauna (samples 6, 4, 20, 19, 18, 125, 126). *Ammonia aoteanus* is a world-wide hyposaline species capable of withstanding considerable variations in salinity. In the Gippsland Lakes it occurs in

salinities down to 5‰ and probably below this value. However, the enormous population numbers in this fauna, coupled with a large specimen size, may suggest that the salinities between 15 and 31‰ represent an optimum for the species. The largest specimens of *Ammonia aoteanus* are 1 mm across, very thick walled, and with thickened raised sutures. Juvenile specimens are also abundant. Less than 1% of the populations from the central lake basins were made up of the species *Bulimina marginata*, *Fursenkoina fusiformis* and *Bolivina* spp. Small numbers of other species near the margins of this fauna reflect transitions to adjacent faunas.

This fauna was more frequently sampled than most, and it was possible to detect some changes in time. In January and March 1970, *Eggerella advena* generally equalled or outnumbered *Ammonia aoteanus* and these were virtually the only species present. In January 1971, one year later, *Ammonia* greatly outnumbered *Eggerella* and buliminids were a minor component. The change to a 'more marine' fauna corresponded with a rise in salinity, from 15.3‰ in

January 1970 to 26.4‰ in January 1971 (Figures from State Rivers Sample Station No. 3).

A variety of assemblages occur around the edge of Fauna 2 which do not fit into any defined fauna. Faunas on the shallow sandy lake margins are usually sparse. Most are dominated by *Ammonia aoteanus* with *Miliammina fusca* and/or *Ammobaculites barwonensis* (e.g. in Purran Corner — samples 259 and 260). Faunas in the northwest corner of Lake King (samples 73-79) are sparse but varied mixtures of *Ammonia aoteanus*, *Eggerella advena*, *Ammobaculites barwonensis*, *Martinotiella* cf. *communis* and *Criboelphidium poeyanum*. *Ammonia aoteanus* is the most abundant species, but the samples have little else in common. The area requires more detailed sampling. Off the mouth of the Mitchell River, three samples (35, 36, 219) contain a mixture of faunas. Sample 219 contains a fairly typical Fauna 2. Samples 35 and 36 have a high content of *Miliammina fusca* and other arenaceous species and appear to be influenced by the faunas of Jones Bay and by the discharge of the Mitchell River.

#### Fauna 3 — CENTRAL LAKES FAUNA with *Nonion depressulum*

Occurring in the central portion of Lake Victoria, this fauna, as the name implies, is a modification of the Central Lakes *Ammonia-Eggerella* assemblage just discussed. Like that fauna, it is confined to the low energy muddy central areas of the lake.

As with Fauna 2 diversity is notably low and *Nonion depressulum* joins *Ammonia aoteanus* and *Eggerella advena* as the only important components. Either *Ammonia* or *Nonion* may be the most abundant species, varying from sample to sample. The percentage of *Eggerella* drops steadily throughout the area of Fauna 3 away from the boundary of Fauna 2. Proceeding from northeast to southwest the percentage of *Eggerella* decline as follows (see Figs. 4 and 5 for locations):

Sample No.	% <i>Eggerella advena</i>
64	59
57	23
63	37
59	20.4
60	20.5
62	13
123	2
110	9.5
173	4.7
111	13.5

*Eggerella advena* is rare in Fauna 4, to the southwest, and is not seen further from the sea than the southwest end of Lake Victoria.

Other species which occur in very small numbers in more than one sample are: *Textularia* sp.,

*Criboelphidium poeyanum*, *Elphidium articulatum*, *Elphidium oceanensis* and *Virgulinea fragilis*. Total numbers of foraminifera in samples attributed to this fauna are low, with almost all totals below 1,000.

Salinity readings from State River Station 6 (which is located roughly near sample 63) during months of collection ranged between 23 and 28‰. Two water samples from shallower areas adjacent to the fauna, gave readings of 16.2 and 22.1‰. The overall impression of this fauna is that it is a fringe variant of Fauna 2, probably reflecting slightly lower salinities.

Marginal faunas from the sandy, wave-agitated edges of this area differ from those of the central lake area, where the substrate is of black clay. *Nonion depressulum* is reduced in numbers, or absent, in the higher energy conditions. *Miliammina fusca*, which is absent in the low energy central lake samples, is important in the higher energy marginal samples.

#### Fauna 4 — SOUTHERN LAKE VICTORIA

This poorly characterised fauna at the southwestern end of Lake Victoria contains very few specimens and is included here only because it appears to cover a fairly large area (see Fig. 5). This fauna is dominated by *Ammonia aoteanus*, with a fairly wide variety of other calcareous and arenaceous species. *Elphidium oceanensis* occurs in most samples but is not seen elsewhere in the lakes. Calcareous species include *Criboelphidium poeyanum*, and occasional *Nonion depressulum*. Arenaceous species include *Miliammina fusca*, *Eggerella advena*, *Ammotium salsum*, *Martinotiella* cf. *communis*, and *Trochammina inflata*. These arenaceous species reflect the influence of adjacent McLennans Straits (*Ammotium* fauna) and Lake Wellington beyond (Fauna 5).

No sample contains more than 1,000 specimens per 20g, and most contain fewer than 300. Samples in the southeastern half of the lake (numbers 238, 119, 174) are barren and several others are almost barren. The area has not been sampled in sufficient detail to define precisely the areal extent of the fauna, or to detect nearshore variations. No data on salinity was collected for this area. Presumably it is generally intermediate between the values of the northern end of McLennans Straits (17-22‰) and those of the central part of Lake Victoria (23-28‰).

#### Fauna 5 — INNER LAKES

The inner lakes faunas are composed of euryhaline species which tolerate the lowered and fluctuating salinities due to river discharge at the most inland parts of the lakes system. Of the three recognisable faunas two are entirely arenaceous, and one is a mixed calcareous/arenaceous assemblage.



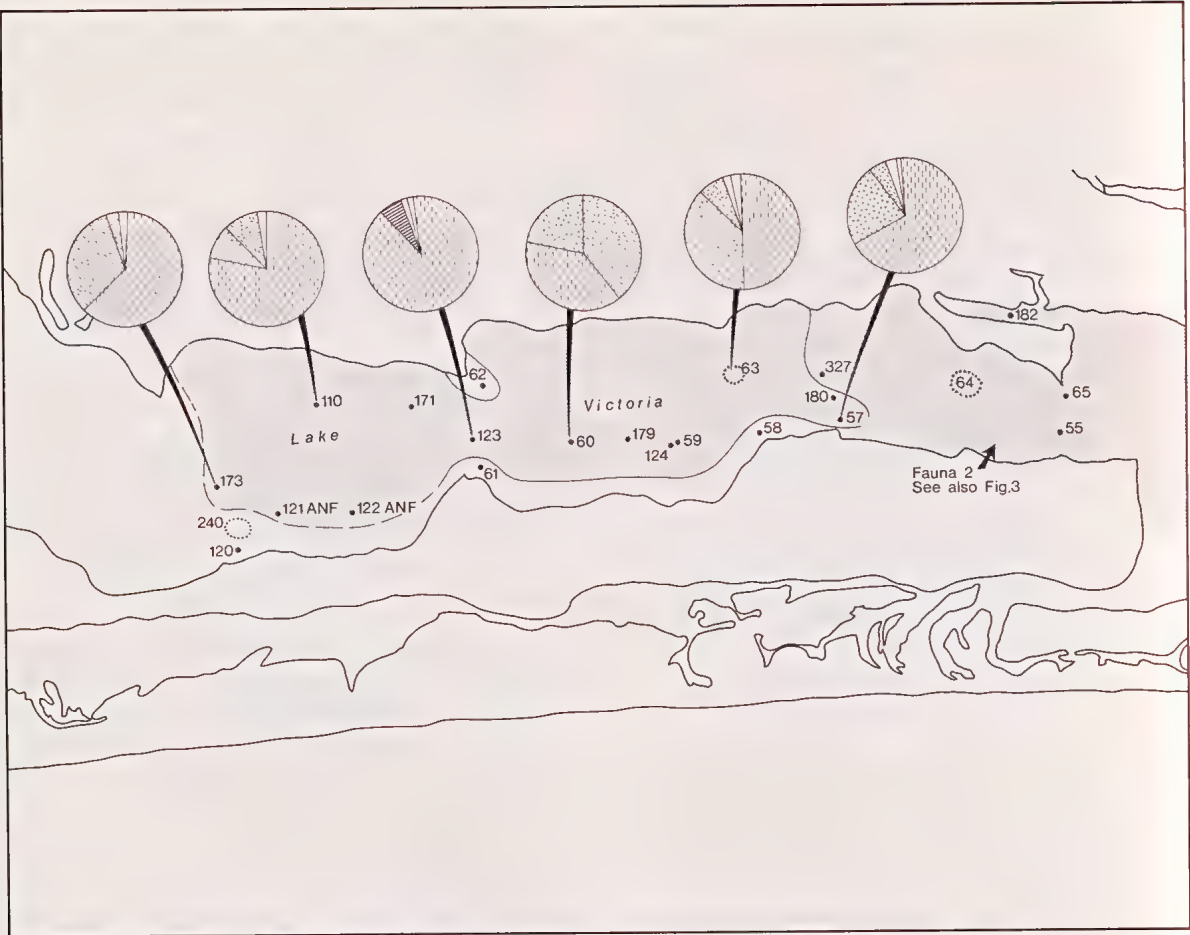


FIG. 4 — Fauna 3: Central Lakes Fauna with *Nonion depressulum*.

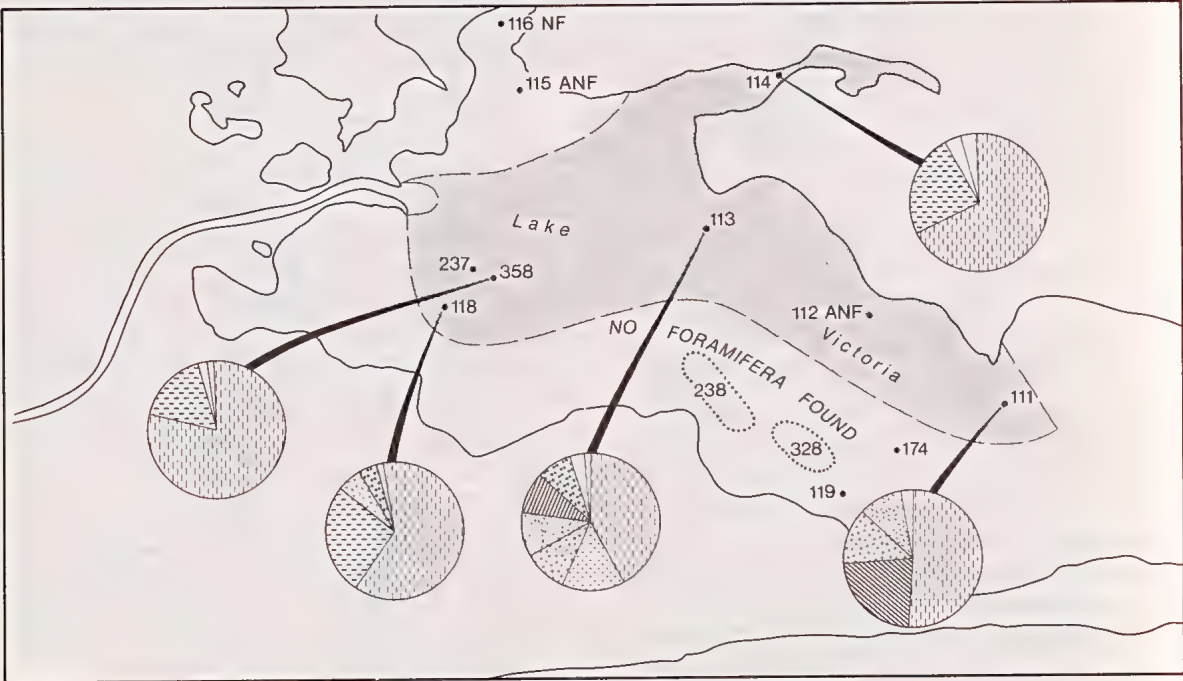


FIG. 5 — Fauna 4: Southern Lake Victoria Fauna.

Fauna 5A — Arenaceous: *Trochamminita*

At the time of this survey, it was confined to small areas in Lake Wellington, namely, a bay on the south side (Poddy Bay), and an area adjacent to the entrance channel (McLennans Straits) (see Fig. 6). Both areas are in shallow water (0.6-1.6 m), with a bottom of sand mixed with minor black mud. Current action and water circulation are active at the latter site. Fresh water from the adjacent Latrobe River probably has a considerable influence on Poddy Bay.

Fauna 5A is the 'least marine' of all the faunas encountered in this survey. It consists of 40% to 78% of *Trochamminita irregularis*. The remainder of the fauna is composed of *Milliammina fusca* and *Ammonium salsum*, with minor *Reophax barwonensis*, *Martinotiella* cf. *communis* and *Trochammina inflata*. Some of the specimens of *Milliammina fusca* and *Trochamminita irregularis* occur as aberrant forms with greatly extended or irregular terminal chambers. The organic internal linings of *Ammonia aoteanus* are also present in one sample. The occurrence of these linings is discussed in connection with Fauna 5B.

No salinity readings from Poddy Bay were available. At the nearest State Rivers water sampling station in Lake Wellington (Station 11), salinities ranged from 0.35 to 5.5‰ at a time when typical faunas of this group were collected in Poddy Bay. Values at the entrance to McLennans Straits (the second area of Fauna 5A) in 0.5 m of water were probably a little above the surface water reading of 0.6‰ for this location (State Rivers Station 8 — April 1971). These salinity values from areas adjacent to Fauna 5A suggest that the fauna flourishes in water that is only slightly brackish.

The pH of 6.0 measured for Fauna 5A in Poddy Bay was one of the lowest recorded during the survey. This appears to be the important factor excluding the calcareous tests of *Ammonia aoteanus*, which is capable of tolerating low salinities. The presence of organic inner chamber linings from *A. aoteanus* in sample 232 indicates that the species moved into the area and that complete dissolution of the calcium carbonate shell wall took place. It seems unlikely that this species could survive for any period, or reproduce, under these



FIG. 6 — Fauna 5A: Inner Lakes Arenaceous Fauna.





salinities during sampling months fell between 5 and 12 parts per thousand.

Several pH readings of 6.5 were obtained from samples of this fauna. Significantly, specimens of *Ammonia aoteanus* are extremely thin walled and lacking in calcareous ornament. Many specimens have their calcareous tests partially or wholly dissolved, leaving only the brown organic chamber lining in the sediment (Pl. 29, figs. 1, 2) similar to those illustrated by Quilty (1977). It seems that a pH of between 6.0 and 6.5 represents an environmental cut-off point for the survival of the species. It can survive at 6.5, but it is not known whether the species would reproduce at this pH value. Repeated migration of juveniles from Lake Victoria in strong tidal currents is a possible mechanism for the maintenance of the population numbers.

**Fauna 5C: Mainly Arenaceous: *Martiniella*/*Miliammina*/*Ammobaculites*/*Ammonia***

This fauna occupies the northern extension of Lake King, an area known as Jones Bay. Like Lake Wellington, this almost closed body of water has two major rivers contributing fresh water to it, and also like Lake Wellington, it is shallow (1-2 m), muddy, and constantly stirred by wind-induced waves. The fauna is similar to that of Lake Wellington, being largely arenaceous, but this area is inhabited by more species. *Martiniella* cf. *communis* (common in Lake Wellington) is the most important form here, making up

22% to 79% of faunas. Other abundant arenaceous species include *Miliammina fusca*, *Ammobaculites barwonensis*, *Ammotium salsum*, and rare *Eggerella advena*, *Trochammina inflata*, and *Trochammina irregularis*. Calcareous species include small percentages of *Ammonia aoteanus*, and rare *Criboelphidium poeyanum*. The number of specimens varies from under 50 to as many as 2200 and 4800 in two samples located directly outside the two entrances to the Mitchell River. This probably reflects a higher concentration of nutrients brought in by the river.

The only salinity reading available is 9.5‰ in a sample just outside the upper entrance to the Mitchell River. It seems probable that the average salinity further down the bay towards Lake King would be a little higher than this. The only pH value known for the area occupied by the fauna is a reading of 4.2 in sample 28, the same sample as the salinity reading above. The predominance of arenaceous forms suggests that a value of 6.5 or below is likely over most of this area. Of particular interest is the presence of sheet-like bryozoa in sample 30 (see Fig. 8; Pl. 29, fig. 15), in a turbid brackish environment.

#### **Fauna 6 — HIGH ENERGY CHANNELS**

These comprise two connecting channels between lakes, each with considerable tidal current flow. Their faunas are predominantly or wholly arenaceous, but composed of different species.

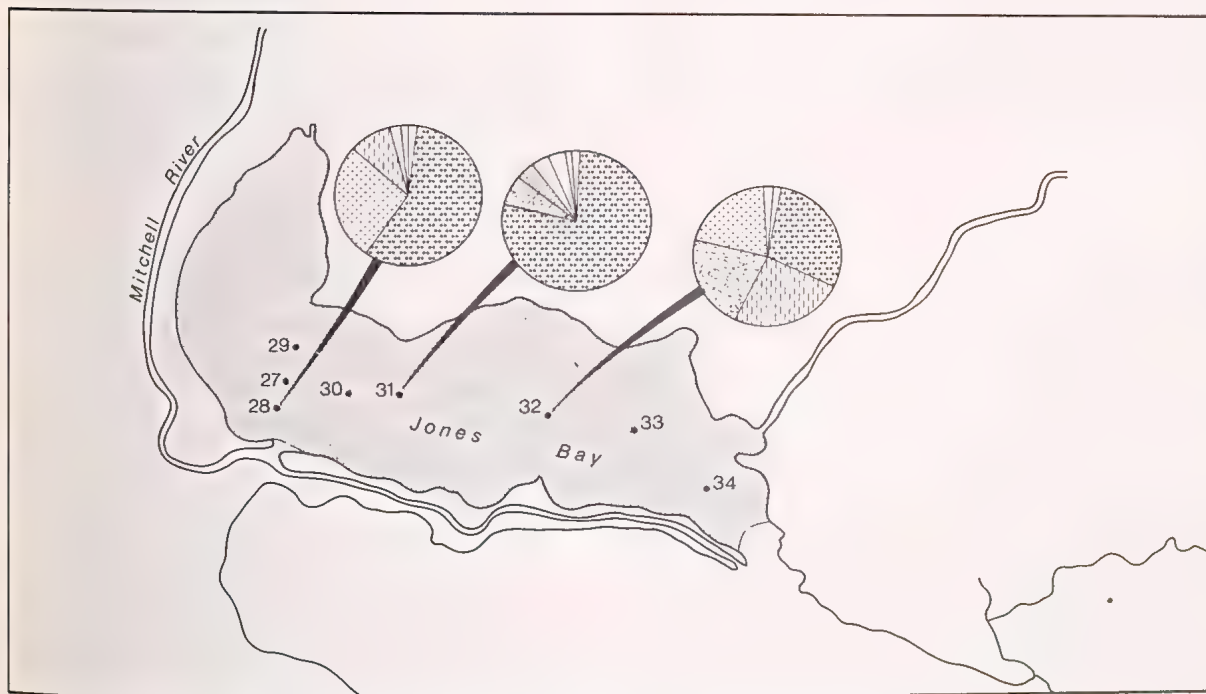


FIG. 8 — Fauna 5C: Inner Lakes Dominantly Arenaceous Fauna.



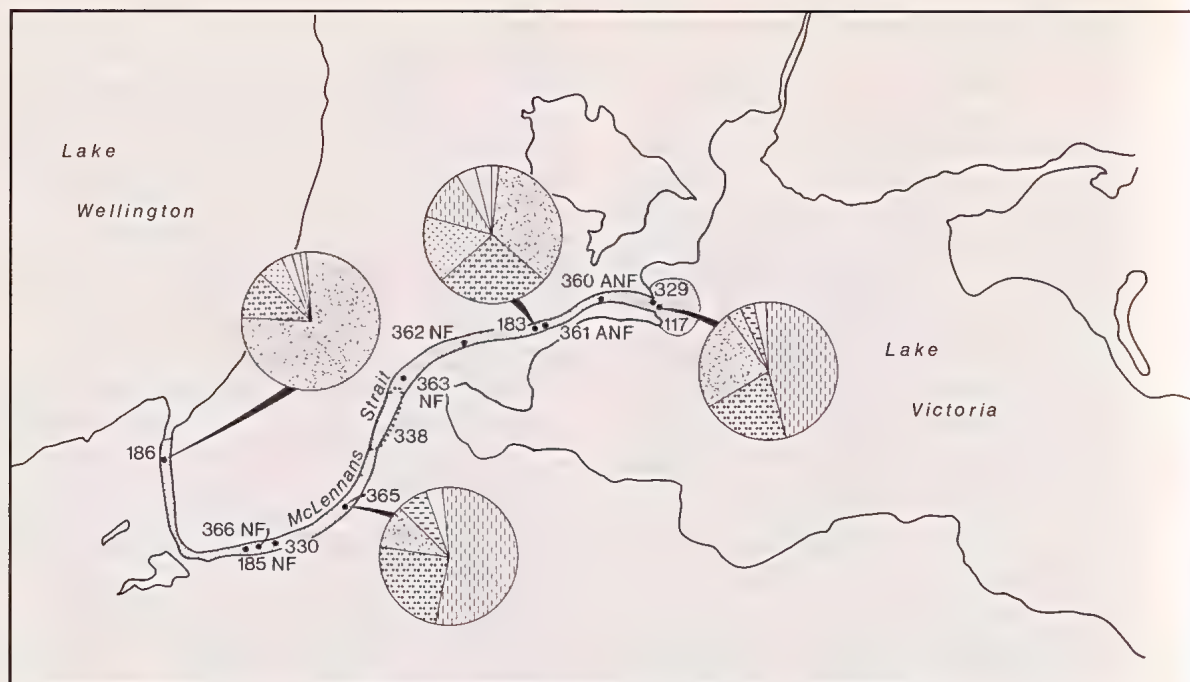


FIG. 9 — Fauna 6A: High Energy Channels: McLennans Strait.

*Fauna 6A: McLennans Strait: Ammonia/Ammotium*

McLennans Strait is a narrow steep-sided channel up to 10 m deep cutting through low swampy land between Lake Wellington and Lake Victoria (see Fig. 9). The channel floor appears to be scoured bare in many places. Many tows of the dredge brought up no sediment, and repeated efforts brought up only very small samples of silt and sand. Salinity figures are given from State Rivers Station 7 at Hollands Landing (sample location no. 360 — see Fig. 9).

Date		Salinity ‰ (Bottom Water Readings)
January	1970	4.46
March	1970	15.00
January	1971	2.72
April	1971	20.20
April	1972	19.50
December	1972	17.50
April	1973	22.24

The figures (for months in which samples were collected) range from 2.7‰ to 22.2‰, with the higher figures in April. The figure for December 1972 (17.5‰) differs considerably from that of sample no. 338 (26.9‰), which was collected in the same month. The figures emphasize the considerable salinity variations to be expected in the channel connecting the two largest lakes in the system.

The numbers of foraminifera in this channel were low, a maximum of 327 being recovered from

any one sample. Half the samples were barren, or almost barren. The fauna is dominated by *Ammonia aoteanus*, but with important numbers of *Ammotium salsum* and *Martinotiella* cf. *communis*. The abundance of *Ammotium salsum* distinguishes the fauna from that of Lake Wellington to the west, where *A. salsum* is occasionally present, and from the Lake Victoria faunas, from which it is almost absent. Other species in the McLennans Strait fauna include *Miliammina fusca*, *Criboelphidium poeyanum*, *Trochammina inflata*, *Trochammina irregularis*, *Haplophragmoides canariensis* and *Elphidium oceanensis*.

*Fauna 6B: McMillan Strait: Eggerella/Ammobaculites/Miliammina*

McMillan Strait, connecting parts of Lake King and Lake Victoria, is a relatively short channel with a strong tidal flow and floor of black silt and sand. The faunas comprise about 90% arenaceous species. *Eggerella advena*, one of the dominant forms of the adjacent central lakes fauna (Fauna 2) is the most abundant species. Others are *Miliammina fusca*, *Trochammina inflata*, *Martinotiella* cf. *communis*, and *Ammobaculites barwonensis*. *Ammonia aoteanus* is unusually sparse (less than 10% in all samples). The salinity is a little lower than that of the adjacent central lakes. Two readings of 19.4 and 22‰ were recorded at State Rivers Station 5 during sampling months (March 1970, April 1971). The high velocity and san-

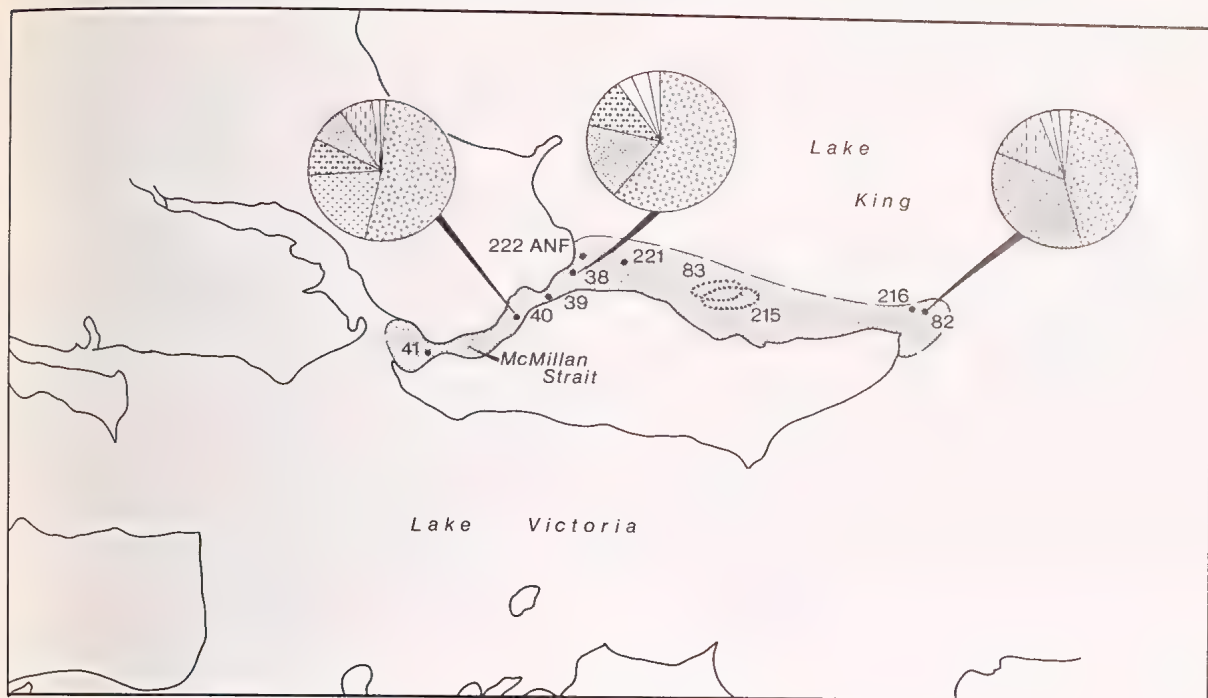


FIG. 10 — Fauna 6B: High Energy Channels: McMillan Strait.

dier substrate may also be important environmental differences.

This fauna also extends out into Lake King, particularly along the northern side of Raymond Island. The sandy substrate is the only known difference between this area and the central part of Lake King.

#### Fauna 7 — LOW ENERGY ENVIRONMENTS

The peripheral Lakes Bunga and Reeve are long narrow bodies of water separated from Bass Strait by a coastal strip of sand dunes. Although under tidal influence, they are out of the main water circulation pattern of the lakes. These lakes support two distinct microfaunas, one calcareous and one arenaceous. It is suspected that light penetration and water depth, salinity and substrate, may all control the distribution of these faunas within each lake.

##### Fauna 7A: Lake Bunga: *Ammobaculites*

Lake Bunga, the larger lake, is 15.4 km long and less than 270 m wide, 4.5-6.0 m deep, and floored by black mud overlain by a dense cover of filamentous algae. Over most of the lake, for the entire four-year period of the study, *Ammobaculites barwonensis* was the dominant, and sometimes the only foraminifer present. The other principal component was *Reophax barwonensis*. Minor species occasionally present were *Millammina fusca*, *Martinotiella* cf. *communis* and *Ammobaculites agglutinans*. For this fauna, the only salinity value known is one of 17.4‰.

##### Fauna 7B: Lake Bunga: *Elphidium*

At the northeastern end of Lake Bunga, variation in the environment results in a completely different fauna. Much higher salinities of 27 to 31.6‰ were encountered, probably due to evaporation. The water was extremely shallow (0.3-0.9 m), and the bottom was composed of silt or sand, largely free of weed cover. The fauna was composed of *Criboelphidium poeyanum* and *Elphidium articulatum*. Green algae are conspicuous in the chambers of the foraminifera. This fauna is associated with shallow areas of high light penetration.

The same fauna was also found living in extreme environmental conditions in small, shallow (less than 0.3 m depth) pools connected to Lake Bunga, at Bunga Head (see Fig. 11 — samples 322 to 325). The salinity in these pools was 40‰ and a saline crust was forming on exposed mud flats at the edge of the pools. The water temperature was 28°C, the pH of the water 8.0, and the pH of the mud surface 9.5. Despite the fine-grained, gelatinous nature of the sediment forming, the pools were clear due to their small size and protected location. The fauna was composed almost entirely of *Elphidium articulatum*, with transitional forms resembling *Criboelphidium poeyanum*. It seems possible that the whole population represented a single, rather variable species, and not two separate genera as implied by the taxonomy. In four samples over 60% of the specimens were living when collected. The fauna demonstrates the high tolerance to variations



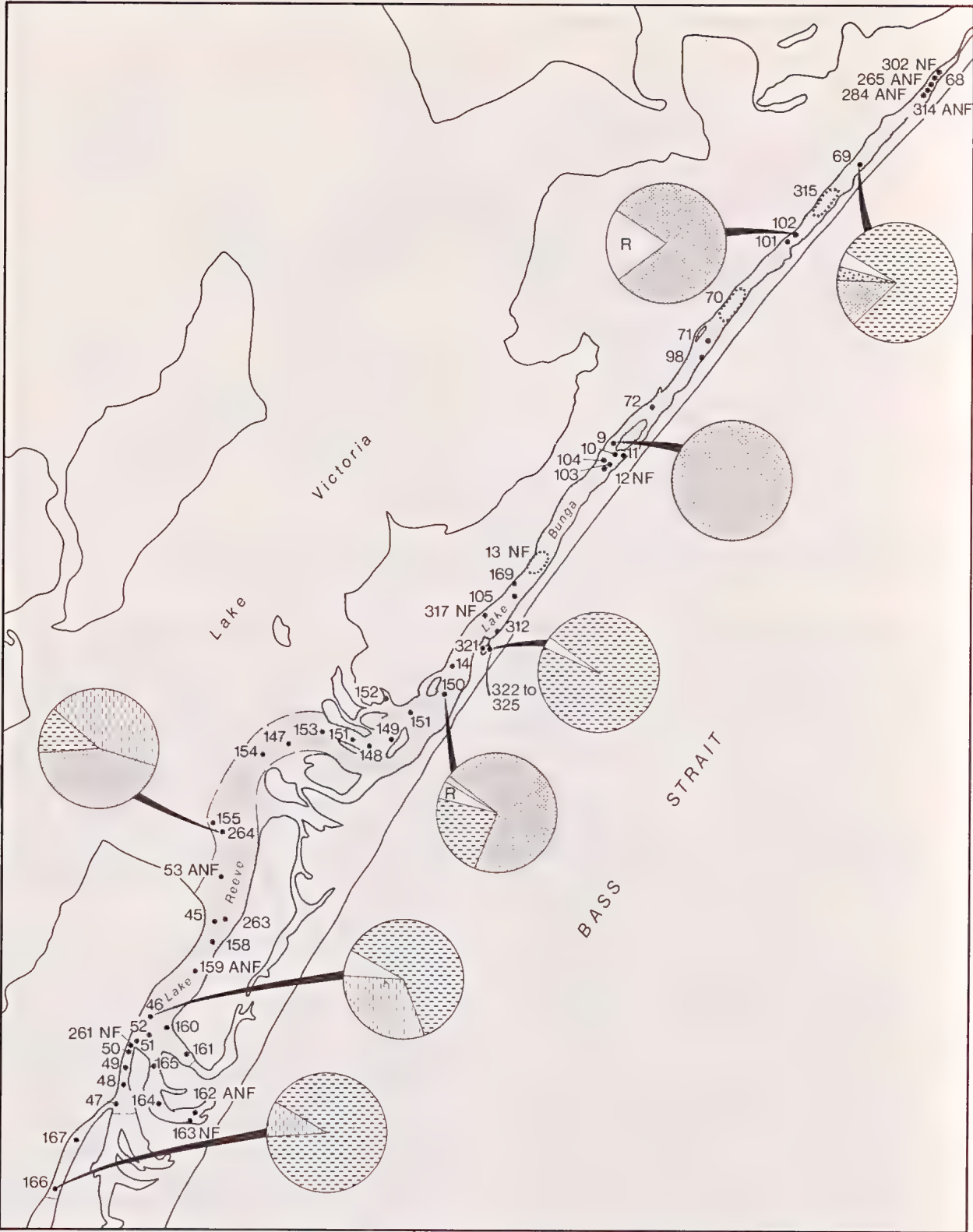


FIG. 11 — Fauna 7A, 7B and 7C: Peripheral Lakes: Lake Bungar and Lake Reeve.

in salinity characteristic of the unkeeled *Elphidium* group (Murray 1973).

**Fauna 7C: Lake Reeve; *Elphidium articulatum*/Ammonia**

Lake Reeve, although an extensive depression, is largely a string of salt marshes which are dry for much of the year. The water-filled northern end of the lake is less than 1 m deep over most of its area. This end of the lake is broken up into small arms and bays by the complex form of the Pleistocene dune barrier system (see Figs. 1 and 11). The bottom sediment varies from black clay with extremely dense weed beds, to a few areas of shelly sand. The lake is so shallow that little wave motion is generated, since the mats of vegetation almost everywhere reach the water surface. Small depressions between the weed banks provide clear water, undisturbed areas in which faunas of *Elphidium articulatum*, *Criboelphidium poeyanum* and some *Ammonia aoteanus* are present. In the deeper water area adjacent to the entrance of Lake Reeve, the

faunas contain a considerable number of *Ammobaculites barwonensis*, which may have spread from Lake Bunga. Four salinity readings available from samples are 15.3‰, 18.9‰, 22.7‰ and 30.9‰.

#### Fauna 8 — RIVER FAUNAS

The lower parts of three rivers and one creek flowing into the Gippsland Lakes were sampled (see Fig. 12). With the exception of the delta of the Mitchell River, the foraminiferal faunas are extremely sparse. Three samples from the Latrobe River channel were barren. All samples from the Mitchell River above its junction with Jones Bay were barren, or virtually so. The Mitchell River delta channel contained a sparse fauna dominated by *Ammobaculites barwonensis* in the upper part. *Ammonia aoteanus* was present in sample 96, nearer the mouth, where the faunal numbers rose slightly. In the Tambo River also, sample 21, furthest upstream, was dominated by *Ammobaculites barwonensis*, while downstream *Ammonia aoteanus*

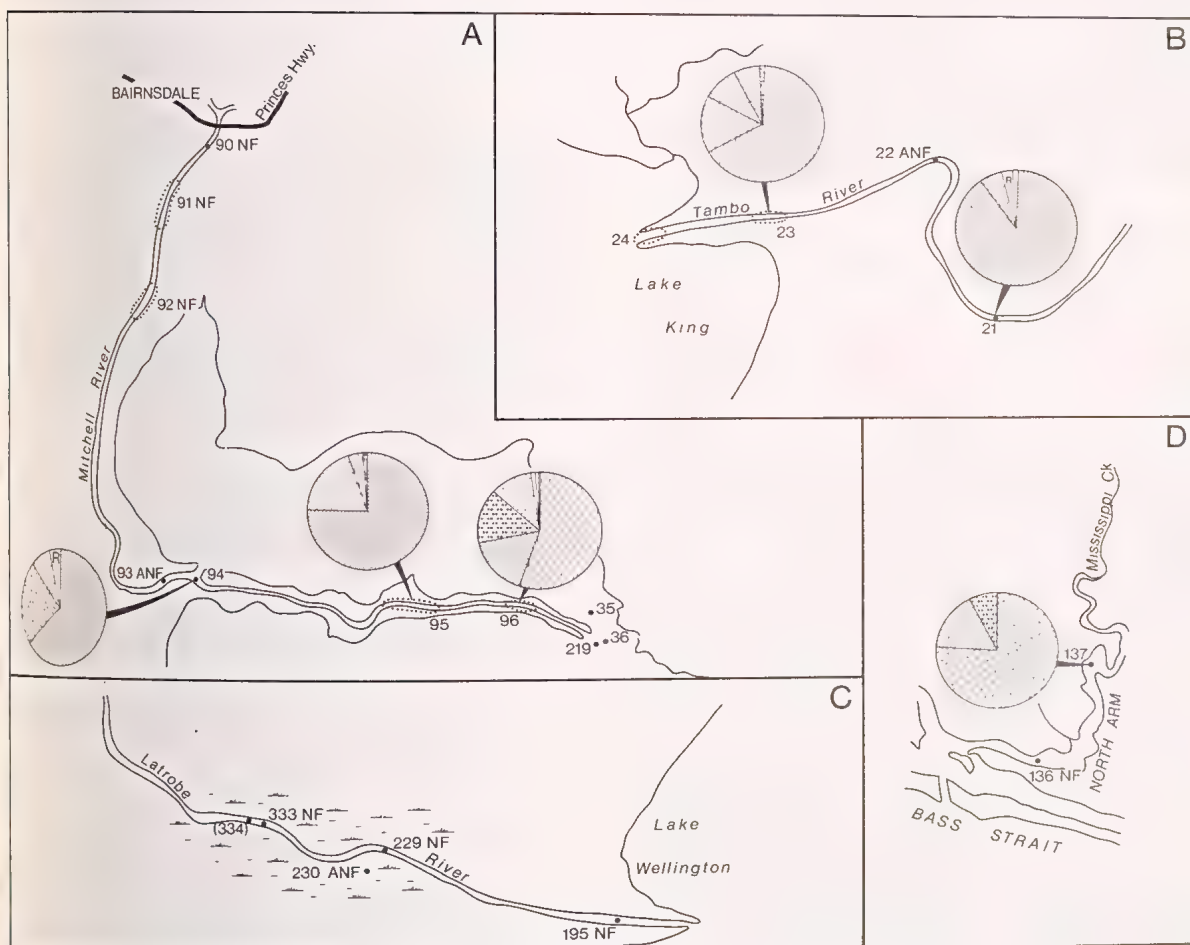


FIG. 12 — River Faunas.



became dominant in the sparse fauna. The only abundant fauna found was at the mouth of the river, where the fauna is transitional to that of the central lakes, Fauna 2.

A single sample from the tidal creek known as the North Arm, north of Lakes Entrance, yielded a small wholly arenaceous fauna. Here *Eggerella advena* was dominant, with *Ammobaculites barwonensis* next in importance. The rivers were not sampled in sufficient detail to draw any conclusions as to the effect of salinity changes on the foraminifera.

It is believed that the lower parts of virtually all the rivers are brackish at times, due to a salt water wedge. This view is based on the salinity figures for the Latrobe, which is the furthest inland of the sampled streams. The absence of foraminifera from the lower part of the Latrobe (and from western Lake Wellington beyond) remains unexplained.

## CONCLUSIONS

Despite the preliminary nature of this survey, and the need for future detailed studies, some observations on the foraminiferal faunas and their environment as developed in the Gippsland Lakes can be suggested.

1) Salinity appears to be the most important single factor controlling the faunal assemblage of an area. The salinity ranges of some important faunas, so far as they can be gauged from the sparse data, are:

	Salinity, ‰
Seaward Fauna 1	20-35
↑ Fauna 2	(12) 15-31
Fauna 3	16-28
↓ Fauna 6A	3-22 (27)
Fauna 5B	0.3-12 (17)
Inland Fauna 5A	0.3-5?

The values in parenthesis ( ) are believed to be atypical.

2) The pH of the substrate appears to be important in determining whether wholly arenaceous, wholly calcareous, or mixed faunas occur. Some tentative observations:

Above pH 8.5	— generally wholly calcareous faunas ( <i>Elphidium</i> )
7.0-7.5	— mixed arenaceous and calcareous faunas.
6.5	— mixed faunas, but with calcareous tests thin walled and showing dissolution effects.
6.0 and below	— either wholly arenaceous faunas, or faunas with small numbers of calcareous species ( <i>Ammonia</i> ) showing severe dissolution effects.

3) The type of substrate in the Gippsland Lakes appears to depend on the energy level produced by the action of waves and tidal currents. The nature of the substrate — whether sand, clay or weed — appears to be of some

importance in determining which one of several species, having similar salinity preferences, will be present. It has been pointed out in discussion of Faunas 2 and 3 that there are differences between the faunas of the central clay and weed-floored lakes, and the faunas of the sandy turbulent nearshore areas. Some of these contrasts between nearby samples are illustrated below:

Area	Sample No.	Substrate	Main foraminifera (in order of abundance)
Lake Victoria (Fauna 2)	81	Clay	<i>Ammonia aoteanus</i> <i>Eggerella advena</i> <i>Nonion depressulum</i>
	82	Sand	<i>Eggerella advena</i> <i>Ammobaculites barwonensis</i> <i>Ammonia aoteanus</i>
Lake Victoria (Fauna 3)	60	Clay	<i>Nonion depressulum</i> <i>Ammonia aoteanus</i> <i>Eggerella advena</i>
	61	Sand	<i>Miliammina fusca</i> <i>Ammonia aoteanus</i> <i>Criboelphidium poeyanum</i> <i>Eggerella advena</i>

Arenaceous species are associated with dense weed beds, or with areas of turbidity. *Miliammina fusca* and *Ammobaculites barwonensis* were found living in abundance in weed beds, and *Martinotiella* cf. *communis* was common in areas of shallow, turbid clay sediments. *Eggerella advena* reaches its maximum numbers in clay substrates, but is also found in sands. Despite its occurrence in weed beds as noted above, *Miliammina fusca* was also found consistently in sandy substrates. *Elphidium* spp. were abundant in sandy nearshore areas.

4) High and low energy environment: a tendency for *Ammotium salsum* and *Trochammina rotaliformis* to be common in areas of current activity has been noted.

5) Variations within this shallow lake system are so small that depth is not, in itself, a factor influencing the faunas. However, variations in depth have a profound influence on whether the lake floor is within reach of the effect of waves. This factor in turn dictates the type of substrate, which to some extent influences the type of foraminifera present.

## TAXONOMIC NOTES

Brief notes on selected species are included, either because their identification presented problems, or because their occurrence is noteworthy from an environmental point of view. Reliance for the identifi-

cations below has been placed on the Catalogue of Foraminifera (Ellis and Messina 1940 *et seq.*).

#### Suborder TEXTULARIINA

##### *Ammobaculites barwonensis* Collins

(Pl. 28, figs. 4, 5, 10-13)

**DESCRIPTION:** The specimens are moderately large (1-1.2 mm in length). The wall is finely agglutinated and fairly smoothly finished. The initial part is close coiled and slightly compressed, with about 5 chambers visible. This is usually the widest part of the test. The uncoiled part of the specimen is variable in shape and number of chambers. The majority of specimens have approximately five chambers, considerably wider than high. They vary from cylindrical to compressed in shape. The aperture is large and circular to elliptical in shape. A minority of specimens have a tendency to become strongly compressed and flabelliform. This may affect all the chambers in the uncoiled portion, or only the latest chambers. In flabelliform specimens the width of the latest chambers often exceeds that of the initial coil. The aperture in such specimens becomes an elongated slit. Up to 10 chambers are present in the uncoiled portion of flabelliform specimens. Continuous variation exists between the typical and flabelliform specimens.

**REMARKS:** This species was described (Collins 1974) from specimens collected on the bank of the Barwon River. Since Collins's small number of specimens do not show the considerable variability of the species, especially the flabelliform character of some specimens, description of the species as developed in the Gippsland Lakes is provided.

The species is much larger and more variable in morphology than the Recent species *Ammobaculites exiguus* Cushman and Bronnimann which is not compressed, and has mostly indistinct sutures. Most specimens of *A. barwonensis* have at least part of their test slightly compressed, and many specimens are markedly compressed while the sutures are always distinct. This species differs from *Ammobaculites agglutinans* (d'Orbigny) which also occurs in the Gippsland faunas (Pl. 28, fig. 9), in being larger, in having a much more involute initial coil, in the compression of the test, and in the tendency to become flabelliform in shape.

##### *Trochammina irregularis* Cushman and Bronnimann

(Pl. 29, figs. 5, 6, 10, 14)

**REMARKS:** The small (?immature) specimens resemble *Jadammina macrescens* (Brady), but intermediate sized specimens begin to develop the irregular terminal chambers of *Trochammina irregularis*, so that the entire population is referred to the latter species.

##### *Martinotiella cf. communis* (d'Orbigny)

(Pl. 29, figs. 4, 9)

*Clavulina communis* (d'Orbigny, 1826); Ellis & Messina, Catalogue of Foraminifera.

*Martinotiella communis* (d'Orbigny); Loeblich & Tappan, 1964: C282, fig. 188, 10a-b.

**REMARKS.** The specimens found have a short trochospiral/triserial stage followed by only two biserial chambers, and usually five uniserial chambers. Occasional specimens have up to eleven uniserial chambers. The chambers are wider

than high, and sutures are well defined. The specimens appear to be referable to *Martinotiella communis* as figured by Brady (Barker, 1960, Pl. 48, Fig. 3, 6-8). Collins (1974) has recorded *Martinotiella primaeva* (Cushman) as very rare in Port Phillip Bay, but not *M. communis*. However, specimens referred to *M. communis* by Taylor from offshore Gippsland waters are more robust and have a smoother, more rounded initial end. In Bass Strait waters off Gippsland, Taylor and Mee (pers. comm.) found *M. communis* only below 220 m, with a peak of abundance at 750 m. The identification of the Gippsland Lakes form as '*M cf. communis*' is therefore tentative.

#### Suborder ROTALIINA

##### *Elphidium articulatum* (d'Orbigny)

(Pl. 28, figs. 6, 7)

*Elphidium articulatum* (d'Orbigny); Murray, 1971: 153, Pl. 63.

##### *Criboelphidium poeyanum* (d'Orbigny)

(Pl. 28, fig. 3, 8)

*Elphidiononion poeyanum* (d'Orbigny); Barker, 1960: Pl. 109, Fig. 22a.

*Criboelphidium poeyanum* (d'Orbigny); Loeblich & Tappan, 1964: C635-6, Fig. 508, nos 3, 4.

**REMARKS:** A small number of specimens intermediate in morphology between *Elphidium articulatum* and *Criboelphidium poeyanum* are present in Fauna 7B developed in small pools at Bunga Head. The specimens are less compressed than *E. articulatum* and are less ornamented along the sutures. They differ from *C. poeyanum* in having less inflated chambers in the last whorl (see Pl. 28, fig. 8).

##### *Ammonia aoteanus* (Finlay)

(Pl. 27, figs. 5, 6; Pl. 29, figs. 1, 2)

*Streblus aoteanus* (Finlay, 1940: 461-462).

*Ammonia aoteanus* (Finlay); Hedley, Hurdle & Burnett, 1967: Pl. 11, Figs. 4A-C, Text-figs. 56-60.

*Ammonia aoteanus* (Finley); Collins, 1974: Pl. 3, Figs. 30a-c.

**REMARKS:** This is the most prolific and widespread species in the Gippsland Lakes, stretching from Lake Wellington to Lakes Entrance. It reaches its acme in Fauna 2. There is a great range in size, from large (1.0 mm diameter) specimens in Fauna 2 to much smaller adults in Fauna 5B. A full range of sizes occurs in each of Faunas 1 to 4. Specimens from arenaceous dominated faunas (5B, 5C, etc.) and from samples with low pH values are smaller, and much thinner walled than those in Fauna 2. This trend towards thinner walls with increasing distance from the sea reaches its maximum in Lake Wellington (Fauna 5B), where many specimens of *Ammonia aoteanus* have undergone partial or complete dissolution of the calcareous wall. The latter specimens survive in the Recent sediments in the form of fragile brown organic specimen linings (see Pl. 29, fig. 2). Low pH values (below 6.5) are presumed responsible for this dissolution.

*Ammonia aoteanus* was described from New Zealand by Finlay, who apparently differentiated it from *A. beccarii* mainly on the narrower less pustulose umbilicus and the complete lack of nodular ornament along the sutures. Hed-



ley, Hurdle and Burdett (1967) say of *A. aoteanus* that 'the umbilical fissures are bordered by clear shell material but no beads or bosses are present along the sutures. When present, the umbilical plug may be distinct or pustulate in appearance'. Collins (1974, Pl. 3, Fig. 30) has figured a specimen of *A. aoteanus* which is fairly strongly pustulate in the umbilical area, but with unornamented umbilical sutures. Gippsland Lakes specimens generally correspond to the description of *A. aoteanus*. However, there is great variability in the form of chamber flaps and pillars developed on the ventral side. Some large specimens entirely lack pillars in the umbilical region, while in others a moderate number of these are developed. Some specimens have numerous small nodules developed in the umbilical fissures between the chambers, and on the umbilical tips of the chambers themselves. These forms appear to be transitional to true *A. beccarii*. Specimens belonging to *A. beccarii* are common in Recent material from Peel Inlet, southwestern Australia in the author's collection. Here, the nodular, sutured *beccarii* form is almost as common as the unornamented *aoteanus* form. Similar specimens were described by Quilty (1977) from Hardy Inlet (extreme S.W. Australia). The specimens referred to *Streblus beccarii* by McKenzie (1962) from the nearby Oyster Harbour were apparently the same form. These Southwestern Australian estuarine faunas are characterized by warm temperate species (especially those of McKenzie) whilst the Gippsland Lakes faunas are typically cold temperate. It is postulated here that *A. aoteanus* is a cool temperature water morphotype of *A. beccarii*.

***Virgulinella fragilis* Grindell and Collen, 1976**

(Pl. 27, fig. 9)

*Virgulinella fragilis* Grindell & Collen, 1976; Pl. 1.

REMARKS: This species is rare in Fauna 2. Recently described from New Zealand, this seems to be its first record from Australian waters.

## ACKNOWLEDGMENTS

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## DESCRIPTION OF PLATES 26-29

## PLATE 26

## FAUNA 1: SEMI-MARINE

1. *Quinqueloculina seminulum* (Linné); Sample 144 X 110. 2. *Quinqueloculina tropicalis* Cushman; Sample 144 X 132. 3. *Miliolinella subrotunda* (Montagu); Sample 144 X 190. 4. *Quinqueloculina* cf. *ferussacii* d'Orbigny; Sample 128 X 83. 5. *Rosalina* sp.; Sample 143 X 215. 6. *Bolivina variabilis* (Williamson); Sample 18 X 232. 7. *Discorbinella subbertheloti* (Cushman); Sample 143 X 185. 8. *Pileolina patelliformis* (Brady); Sample 143 X 237. 9. *Trochammina rotaliformis* Heron-Allen and Earland; Sample 242 X 118. 10. *Elphidium advena* (Cushman); Sample 144 X 145. 11. *Elphidium macellum* (Fichtel and Moll); Sample 142 X 94.

## PLATE 27

## FAUNA 1 (continued) and FAUNAS 2-3; CENTRAL LAKES

1. *Bolivina pseudoplicata* Heron-Allen and Earland; (Faunas 1-2); Sample 128 X 200. 2. *Bolivina striatula* Cushman (Faunas 1-2); Sample 18 X 174. 3. *Bulimina marginata* d'Orbigny (Faunas 1-2); Sample 128 X 132. 4. *Textularia* sp. (Faunas 1-3); Sample 64 X 232. 5, 6. *Ammonia aoteanus* (Finlay) (all Faunas) opposite sides of different specimens; Sample 126 X 91. 7, 10. *Eggerella advena* (Cushman) (most Faunas); 7: Sample 126 X 124; 10: Sample 126 X 83. 8. *Bulimina gibba* Fornasini (Faunas 1-2); Sample 19 X 116. 9. *Virgulinella gracilis* Grindell and Collen (Faunas 2-3); Sample 55 X 141. 11, 12. *Nonion depressulum* (Walker and Jacob) (all Faunas, typical of Fauna 3); 11: Sample 173 X 75; 12: Sample 173 X 83.

## PLATE 28

## FAUNA 4: CENTRAL LAKES

- 1, 2. *Elphidium oceanensis* (d'Orbigny) 1: Sample 113 detail, X 348; 2: Sample 113 X 108.

## FAUNAS 7B, 7C: PERIPHERAL LAKES

- 3, 8. *Criboelphidium poeyanum* (d'Orbigny) (all Faunas, but typical of 7B, 7C) 3: Sample 30 X 166; 8: Sample 128 X 207. 6. *Elphidium articulatum* (d'Orbigny) (several Faunas, but typical of 7B, 7C); Sample 322 X 149. 7. *Elphidium articulatum* transitional to *Criboelphidium poeyanum* (compare with figure 8); (typical of Fauna 7B); Sample 322 X 100.

## FAUNA 7A: PERIPHERAL LAKES: LAKE BUNGA

- 4, 5, 10-13. *Ammobaculites barwonensis* (several Faunas, but typical of 7A). 4: Side view of specimen with elongated aperture; Sample 30 X 91. 5: Typical specimen; Sample 11 X 64. 10: Fairly common form, with eight chambers in uniserial portion of test; Sample 11 X 58. 11: Large flabelliform specimen. All gradations between fig. 10 & 11 occur. Sample 30 X 58. 12: Specimen with slightly compressed early uniserial chambers, becoming rounded in profile in final chamber; Sample 102 X 100. 13: Detail of aperture of figure 12 X 310. 9. *Ammobaculites agglutinans* (d'Orbigny) (several Faunas); Sample 83 X 103.

## PLATE 29

## FAUNAS 5B, 5C: INNER LAKES — LAKE WELLINGTON AND JONES BAY

1. *Ammonia aoteanus* (Finlay) Spiral view of partially decalcified specimen, typical of Lake Wellington Faunas (5B); Sample 197 X 240. 2. *Ammonia aoteanus* (Finlay) Umbilical view of wholly decalcified specimen, showing organic inner lining of the chambers. Lower part of the specimen is obscured by a layer of glue. Sample 232 X 198. 3. *Miliammina fusca* (Brady); Sample 226 X 75. 4, 9. *Martinotiella* cf. *communis* (d'Orbigny) 4: Sample 30 X 121. 9: Sample 197 X 108. 7. *Reophax barwonensis* Collins 7: Typical specimen, with bulbous initial chamber Sample 11 X 89. 15. Bryozoan Sample 30 X 10.

## FAUNA 5A: INNER LAKES

- 5, 6, 10, 14. *Trochammina irregularis* Cushman and Brönnimann 5: Large specimen with multiple apertures; Sample 196 X 66. 6: Large specimen with irregular coiling; Sample 232 X 75. 10: Typical specimen with streptospiral coiling; Sample 196 X 75. 14: Side view; Sample 196 X 55. 8. *Reophax barwonensis* Collins 8: Form with test built of large sand grains and diatoms; Sample 196 X 58. 11. *Miliammina fusca* (Brady). Specimen with embracing chambers, slightly longer than half the whorl in length, typical of Fauna 5A; Sample 196 X 108.

## FAUNA 6A: HIGH ENERGY CHANNELS

- 12, 13. *Ammotium salsum* (Cushman and Brönnimann) (many Faunas, but common in 6A) 12: Sample 186 X 83. 13: Sample 186 X 70.



PLATE 26



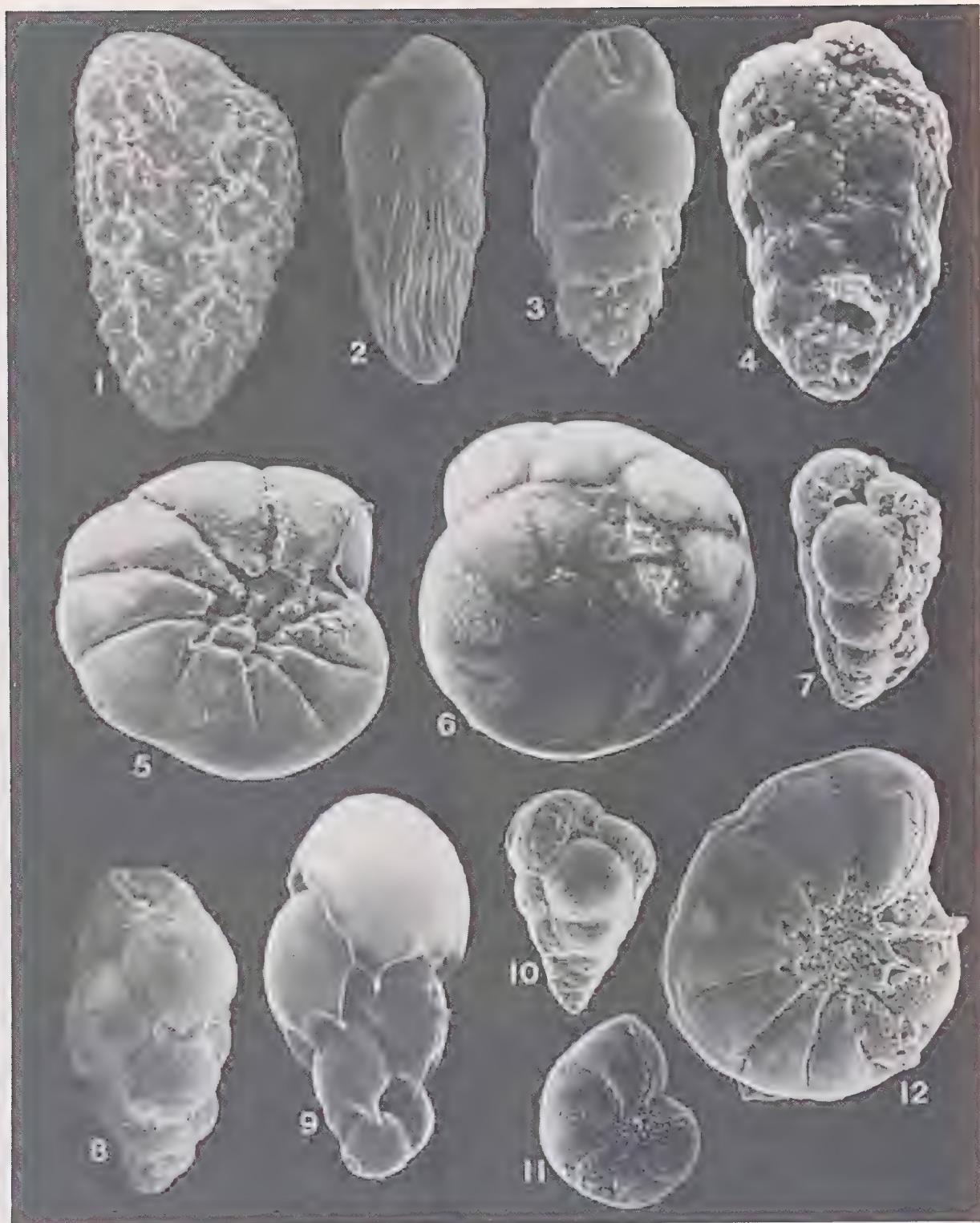


PLATE 27

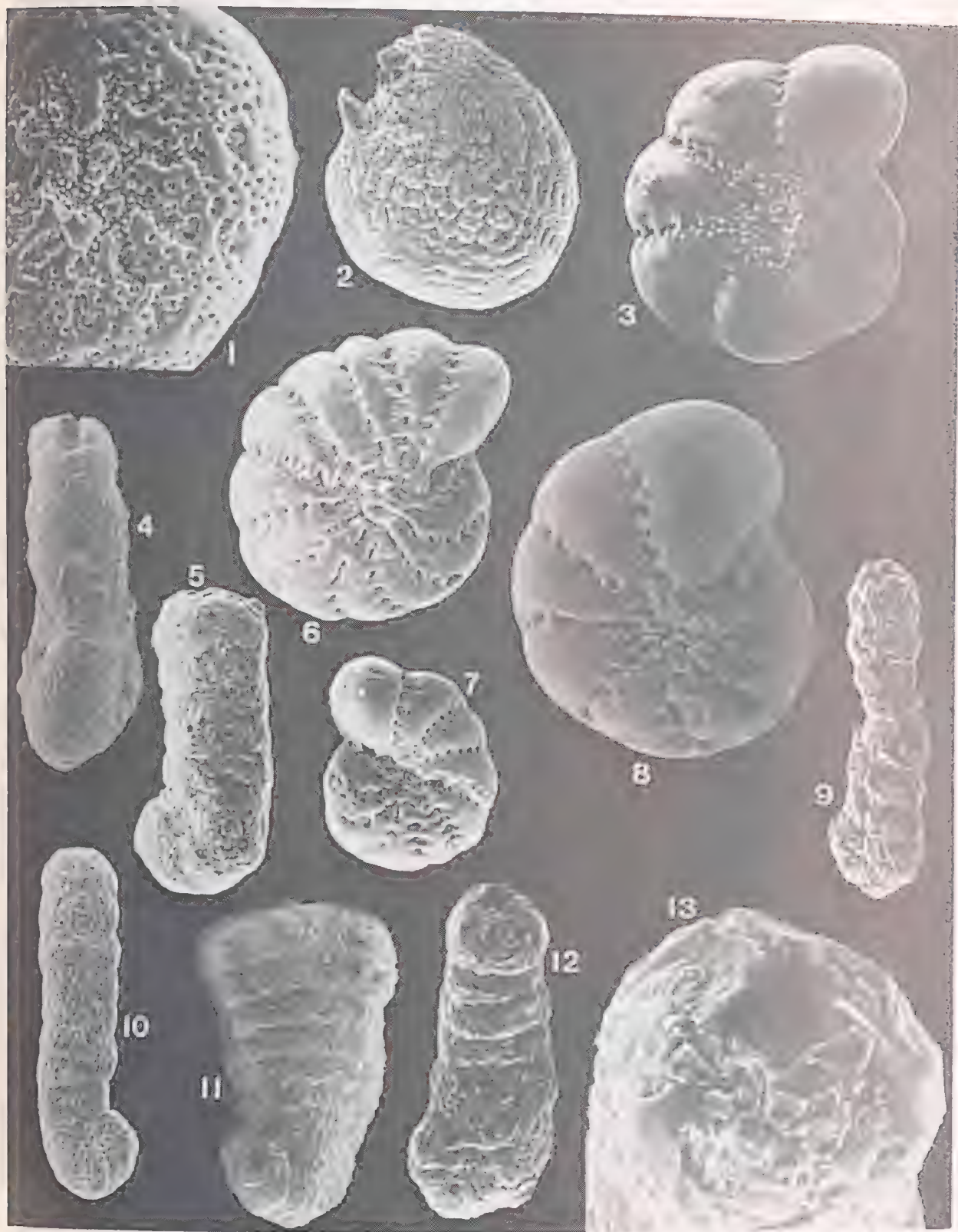


PLATE 28





PLATE 29

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# ABRIDGED REPORT OF THE COUNCIL

FOR THE YEAR ENDING 8 MARCH, 1979

## MEETINGS AND LECTURES

During the year, nine Ordinary and one Joint Meeting were held.

MARCH 9—After the Annual General Meeting: Joint Meeting with the Institute of International Affairs, Victorian Branch. Dr. V. Prescott spoke on 'The Law of the Sea' and Dr. D. E. Bottrill on 'The Past, Present and Future of Australian Seafood Processing and Marketing'.

APRIL 13—Dr. B. Window spoke on 'Solar Energy Thermal Collectors'.

MAY 11—Professor G. M. Badger spoke on 'Planning for Science and Technology in Australia'.

JUNE 8—Professor M. J. Whitten spoke on 'Problems with Modern Methods of Pest Control'.

JULY 13—Dr. W. F. Budd delivered his Medal Lecture, 'The History of the Antarctic Ice Sheet'.

AUGUST 10—Professor R. D. Brown delivered his Medal Lecture, 'Search for the Origin of Life'.

SEPTEMBER 14—Professor J. F. Lovering delivered his Presidential Address, 'The Resource Potential of Antarctica'.

OCTOBER 12—Dr. E. C. F. Bird spoke on 'Recent Changes on the Victorian Coast'.

NOVEMBER 9—Soiree. Mr. F. R. Blanks spoke on 'Old Ears and New Music'. Dr. N. D. Hallam presented a short film, 'A Resurrection Plant'. Exhibits were displayed by the School of Zoology, University of Melbourne, the Departments of Zoology and Botany, Monash University; the Department of Botany, La Trobe University; the Royal Botanic Gardens; the National Museum; ICI Australia Ltd.; CSIRO Division of Applied Geomechanics.

DECEMBER 2—Professor R. Bruce Knox spoke on 'Grass Pollen and Allergy'.

## MEMBERSHIP at 28th February 1979:

Honorary Life Members 3, Life Members 42, Ordinary Members 541, Associates 56, Suspense List (addresses not known) 10, Total 652.

Council recorded with regret the deaths of Sir Robert Menzies (Honorary Life Member), Professor E. J. Hartung and Dr. D. E. Thomas (Life Members), Mr. L. Adams (Vice-President), Mr. G. A. Atkins, Sir Walter Bassett, Mr. H. C. Chipman, Mr. J. R. English, Mr. R. C. Seeger and Dr. W. Strauss.

## PROCEEDINGS

In December 1978 the Society published Volume 90 (Parts 1 and 2 in one cover) at a net cost of \$13,887, after receipt by the printer of Book Bounty amounting to \$4463.

Council acknowledges with gratitude grants from CSIRO, the University of Adelaide, and the Departments of Minerals and Energy of South Australia and Victoria, towards the cost of publication.

## LIBRARY

1873 volumes and parts were received during the year, from exchanges with 53 Australian and 282 overseas organizations.

The late R. C. Seeger has bequeathed to the Library a substantial collection of books on anthropology.

Mrs. D. A. Casey has presented a number of archaeological journals.

573 items were borrowed from the Library (515 in 1977).

Capital donations to the Library Fund in the 1978 financial year totalled \$22,761. The invested capital of the Fund is now \$27,200, with an annual yield of \$3,280. The aim of the Fund is a capital investment of \$50,000. The Council thanks the individuals, organizations and Members who contributed.

## HALL

In addition to the Society and the Royal College of Obstetricians and Gynaecologists, 23 professional and other bodies held 92 meetings in the Hall, compared with 81 meetings by 23 bodies in 1977.

Major items of repairs were plumbing in the Hall (\$144) and painting at the Cottage (\$740).

## GENERAL ASSISTANT

Mrs. I. Sadik relinquished this position on 30th June and vacated the Cottage. Mr. R. Shirra was appointed and took up his duties on 31st July.

## CONGRATULATIONS

Council congratulates Dr. P. G. Law and Sir Ian Potter, who have been elected Fellows of the Australian Academy of Science.

## FINANCE

The year's accounts show a deficiency of \$766 after provision of \$11,800 for publication of Volume 91 of "Proceedings".

## ACKNOWLEDGMENTS

Council, on behalf of the Society expresses its gratitude to the many persons and organizations who have given valuable assistance during the year, including Mr. I. J. Curry, Honorary Auditor; Mr. D. Clarebrough, Honorary Financial Advisor; Mr. L. Masel, Honorary Legal Advisor; The Parks, Gardens and Recreation Department of the Melbourne City Council; Mr. R. Shirra.

L. L. STUBBS

President.













PROCEEDINGS  
OF THE  
ROYAL SOCIETY OF VICTORIA  
VOLUME 92

ROYAL SOCIETY'S HALL  
9 VICTORIA STREET, MELBOURNE 3000

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## INSTRUCTIONS TO AUTHORS

Detailed lists of Instructions are available from the Executive Officer. The following is an abbreviated version only.

Papers considered for publication may be Reviews, Reports of experimental or descriptive research, or Short Communications. Length of Papers may vary; Short Communications should not be longer than 1,500 words.

Two copies of the manuscript, with any accompanying Plates and Figures, should be submitted initially to the Executive Officer at the Society's Hall, 9 Victoria Street, Melbourne, 3000.

**Manuscripts** must be typed on quarto or A4 paper, double-spaced on one side of paper only, and with ample margins. Captions to Text Figures and Explanations of Plates must be attached to the Ms as final pages. Underlining should be restricted to generic and specific names of biological taxa. Measurements must be expressed in the metric system (SI units).

**References** should be listed alphabetically at the end of the paper. Abbreviations of titles of periodicals must conform with those in *A World List of Scientific Periodicals* (1963-4, 4th ed., London, Butterworth). References to books should give the year of publication, number of edition, city of publication, name of publisher. Titles of books and (abbreviated) names of periodicals should be underlined, in the typed list of references.

Maximum size for **Plates** is 15.5 cm x 21 cm. Do not mount photographs. These must have clear definition, may be submitted as either glossy or flat prints, at actual size. The Plate number should be clearly labelled on the back of the photograph.

Line drawing for **Text Figures** should be made in black ink on white card or drawing linen. Maximum size (full page) is 15.5 cm x 21.0 cm: single column width

7.5 cm. Figures are preferably submitted **at actual size**: they may well be drawn larger and photographed by the author to be submitted as glossy prints of required size. Graphic scales must be included with the drawings, and on maps and geographical plan views, compass directions should be indicated. Lettering on Figures must be inserted by the author, and special care is needed to ensure that all letters and numerals are still readable when the Figure is reduced.

Oversized illustrations, tables or maps are accepted for publication as **Foldouts** only with the understanding that the author meet any additional costs involved in their production. Maximum size for **Foldouts** is 21 cm x 31.5 cm.

**Short Tables** will be typeset within the text. Extensive Tables which are likely to cover one page of print should be typed, on an electric typewriter to ensure clarity and evenness, within the dimensions 27.9 cm x 22.5 cm. They should then be photographed to reduce them to full page size, 15.5 cm x 21 cm, and submitted as glossy prints. They will be reproduced photographically, not type-set, and hence must be finally correct when submitted, since they cannot be corrected at the proof stage.

The Society supplies authors with 25 **Reprints** free of charge; joint authors receive a total of 30. Additional reprints may be ordered by returning the order blank which accompanies the galley proofs.

The author of a paper or the Institution from which a paper is received may be requested to contribute towards the cost of publication 15% of the cost of printing that paper.

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In recognition of his long and meritorious service to the Society, the Council of the Royal Society of Victoria determined to honour Edmund Dwen Gill, an honorary life member, by holding a symposium on "Victoria's coasts and continental shelf", a subject to which he has contributed enormously over the years. The symposium was held in the Society's Hall on 11th October 1979 and all papers appearing in Volume 92, number 1 were presented at the symposium either as lectures or as demonstrations. —Hon. Editor

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## EDMUND DWEN GILL

Edmund Dwen Gill has served this Society well—a decade as secretary, five years as treasurer, and two years as president. This formal tribute to his life's work in this venerable hall is felicitous and appropriate, for due honour did not come early from his adopted community. Although Auckland-born, Melbourne has been the seat of his professional life.

Oliver Wendell Holmes remarked that the truest lives are cut rose-diamond fashion, with many facets answering to the many-planed aspects of the world about them. Holmes would approve of Gill.

Perhaps the brightest facet is his humanity, his communion with people, with young people, the common people. Gill graduated in divinity in quest of a career in youth work. A foundation member of the Associated Youth Committee of the National Fitness Council of Victoria, he rose to leadership here, then became Director of Youth Work for Victoria. This humane facet never dulled when his interest in science rose to ascendancy. From his second pulpit in the National Museum he brought science to the people, with many lectures, talks through the country districts and schools, broadcasts, articles in the *Victorian Naturalist*, magazines, and newspapers. He served the National Museum for a quarter of a century from Curator of Fossils to Deputy Director, consistently facing equally his responsibility to advance natural science and to interpret science to the man in the street. It is rare to find in the same person such capacity for sound and original research, and the ability to present science from the rostrum with such simplicity, clarity and charm. A related aspect of Gill's life has been his solid contribution to the chores of organized science. He never sought honorific, prestigious offices, but accepted with grace the laborious tasks as secretary or editor for many sections and committees of ANZAAS, Australian editor for *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, Australian editor for *Pacific Geology*, on various international committees on the Quaternary, and of course for this society. Many here will remember the typically thorough job he did during the centenary of the Society, and the visit of HRH Duke of Edinburgh associated with it. The list is long, and largely unsung.

In the rarer atmosphere of senior science, several bright facets light up. Indeed thirty years ago I heard criticism of Gill that he spread too widely, and sought expertise in too many little-related fields. Certainly his work shows such diversity, but in my judgment all honour to him for so doing. Science herself knows no compartments, and whereas intensive specialists are necessary, we also need some capable of synthetic philosophy woven of many threads. In restricted disciplines the interloper often sees solutions fogged from the specialist. Of course such generalists may not be good specialists, but Gill always showed a patient capacity for taking pains on meticulous detail, and did in fact excel in his several distinct fields.

His first specialty was the Siluro-Devonian stratigraphy of Victoria and Tasmania, which involved him in critical field work and thorough study of fossils; he carefully reviewed the biology of the brachiopods, set up a new family, and recognized several new genera and many species. His work on the Devonian trilobites led to an argument with Ida Browne on the age of the Upper Trilobite Bed at Yass, and it is fair to say that Gill's suggestion is now accepted. He collaborated with world leaders such as G. Arthur Cooper of the US National Museum, Kenneth Caster of Cincinnati on carpoids and with Arthur Boucot on brachiopods. His work led him into the debate about the age of the Victorian Yeringian Series, previously regarded as Wenlockian



(mid Silurian), and Gill joined Ripper, Hill, and Jones in reducing its age to Early Devonian, somewhat athwart the establishment. He extended this work across the Tasman to New Zealand, and thence studied Siluro-Devonian correlations and palaeogeography through Australasia, and thence over all Gondwanaland. This led to his organizing internationally a symposium on the Silurian and Devonian in March 1965 with Professor Boucot as the main speaker. If Gill's work had been limited to his Siluro-Devonian stratigraphy, he would on that alone have earned a significant place in Australian geology.

The next facet of Gill's research is the one that set the theme of this symposium to honour him—shorelines and eustasy. This started as a hobby, but matured into a major mission with significant influence on his life. It brought him into conflict with the mogul (I would award Gill the honours here). His pursuit of eustasy spread from Victoria across Bass Strait and across the Tasman, and inspired his presidential address to this society. The quest also led him down divergent paths—Victorian Quaternary vulcanism; the pre-history of the Australian aboriginal, where he made significant advances, as well as contributing to the Australian section of *Catalogue des Hommes Fossiles*; fluorine dating, which led to papers on dental caries in fossil skulls and dental caries in relation to genetics; radio-carbon dating, which he pioneered in Australia, along with oxygen isotope determination of palaeotemperatures; Quaternary vertebrates, *Diprotodon*, *Thylacoleo* (the marsupial lion), *Macropus* (the giant kangaroo), *Sarcophilus* (the Tasmanian devil), *Vombatus* (the large wombat), *Pygoscelis* (penguins), about each of which he published papers; subdivision of the Australian Pleistocene; Quaternary climatology and palaeogeography and the floras, from diatoms to red gums; and to engineering consultancies, particularly in respect to harbour works here and elsewhere.

Here again he collaborated with other leaders; Rafter and MacIntosh on hominids, George Gaylord Simpson on vertebrates, Fairbridge on eustasy, Dorman on palaeotemperatures, Lester King on geomorphology, and Sweeting on speleology; and again in this field we see his committee-work-horse role: he produced scores of newsletters and literature reviews during his two decades as secretary of the ANZAAS committee on eustasy and shorelines, and during an even longer term as president of the International Union of Quaternary Research committee, and for as many more years as Australian correspondent to international Quaternary journals. He also served for ten years as vice-president of the Anthropological Society of Victoria. If Gill had done nothing else, his Quaternary work alone would have established his stature.

But more is to come. Gill contributed significantly to Cretaceous and Tertiary palaeontology and stratigraphy and palaeoclimatology, and to the definition of the Plio-Pleistocene boundary. Five years ago he was appointed research fellow in the CSIRO Division of Applied Geomechanics to develop quantification of shoreline processes. Gill has always shown a quest for precision—accuracy in semantics, precision in statement, rigorous measurement with fossils or dating or shore levels. Appropriately, later years have matured broader philosophy, in papers and exposition. He had always been a stimulating lecturer. A decade ago he was invited as visiting professor to the California Institute of Technology in Los Angeles.

To Edmund Dwen Gill I say, we appreciate your benevolence, we thank you for your selfless service, we respect your researches, and we honour you as a gentleman.

S. WARREN CAREY

*University of Tasmania*

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## CAUSES OF SEA-LEVEL OSCILLATIONS

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**ABSTRACT:** Excluding local vertical tectonic movements and migration of geoid undulations, sea-level changes imply variation in either the volume of sea water or capacity of the ocean basins.

Volume of ocean basins may be affected by changes either in area or mean depth from the geoid. With constant-radius tectonic models area is a minor variable, but with earth-expansion models, a major variable. Depths are affected by peneplanation (with transfer of sediment from land to sea) and by changes of geothermal gradient to expand or contract the relevant crustal column through paramorphic changes below.

Sea water volume may be affected by accretion of juvenile water from the deep interior, or by variation of the volume of water temporarily sequestered in terrestrial ice, atmosphere, or biosphere. The last two are comparatively trivial. Desiccation of sequestered seas has been suggested as a cause of sea-level rise. The Miocene evaporation of the Mediterranean could have caused a sea-level rise of some 10 m; and extensive salt deposits in the geological record could imply similar effects.

Icebergs, sea ice, and floating ice shelves are irrelevant because of Archimedes Principle. Even ice sheets resting on sediments below sea-level are supported by hydraulic uplift-pressure and are of little consequence. Only land ice is relevant, and isostatic adjustment of load transfer from depleted ocean to glaciated land scales down the sea-level effect by 40%.

Glaciation cycles have been favoured as the prime cause of eustatism. However the work of Vail and his co-authors has shown that the frequency and magnitude of oscillation persists through glacial and non-glacial periods alike. Hence a different major control must operate. Oscillations are skewed. Falls are rapid, rises very much slower. Increase of ocean capacity is the most likely cause of episodic falls. Release of juvenile water the most likely cause of secular rise.

Oscillations occur on time scales, from tens of millions of years through to single years. Palaeontological and radiometric dating through the Phanerozoic cannot differentiate more finely than a million years. Progressive refinement of the eustatic scale signature offers prospect ultimately of precise inter-continental correlations two or three orders better.

### THE GEOID

The surface of the non-perturbed sea is the geoid. This equilibrium surface or mean sea-level is to a first order a sphere, at the second order an oblate ellipsoid, to a third order an oblate spheroid with north-south asymmetry. The fourth order introduces mid-latitude corrections. This may be expressed in gravity terms as:

$$\gamma = c_1 + c_2 \sin^2 \phi + c_3 \cos^2 \phi + c_4 \sin^2 2\phi + c_5 \sin (\lambda - c_6) \sin^2 \phi$$

where  $\phi$  is latitude measured positive in north and negative in south,  $c_1$  is the mean gravity at the equator,  $c_2$  the centrifugal acceleration at the equator,  $c_3$  the north-south gravity asymmetry,

and  $c_4$  the mid-latitude correction. The equator has a crude ellipticity, with sea-level elevations around the Solomon Islands and mid-Atlantic more than 100 m higher than near Ceylon and the central Pacific. (Fig. 1). This ellipticity is expressed by the fifth term, where  $c_5$  is the gravity difference between major and minor axes,  $c_6$  is the longitude of a minor axis of ellipticity, and  $\phi$  and  $\lambda$  are the latitude and longitude variables. Like the earth's gross tectonic features the 'meridians' of this ellipticity are significantly skewed north-side-westward. (Fig. 1). I suspect that these features migrate secularly westward on a humanly long but geologically short time-scale. But this has not been



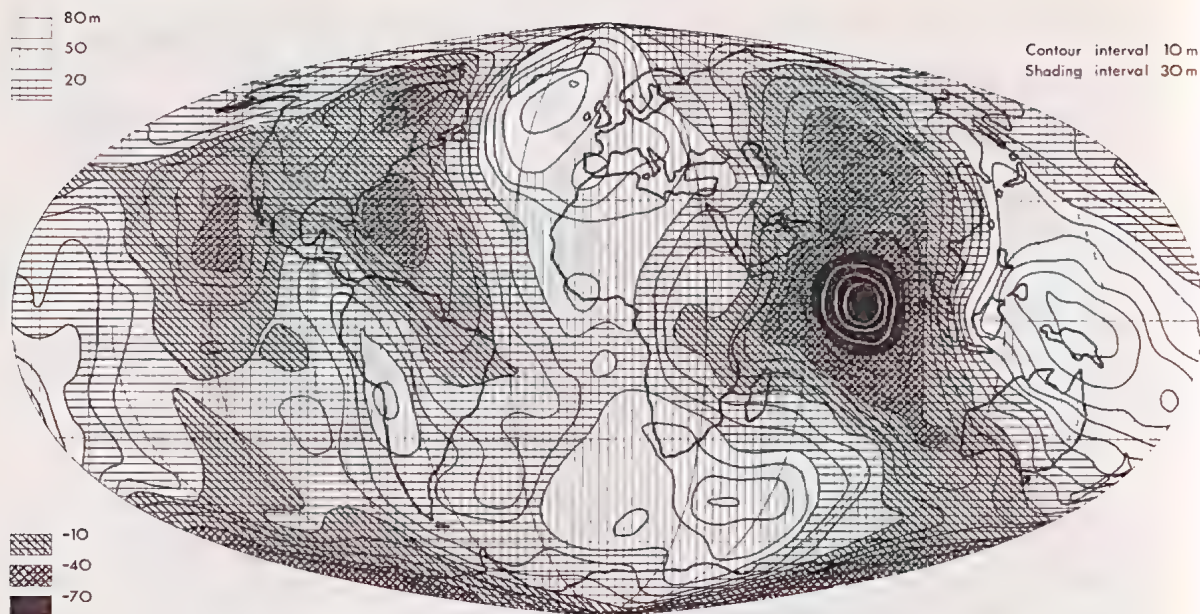


FIG. 1—The Geoid

tested. The geoid is still further modulated on smaller and smaller surfaces, in part permanent because of density heterogeneity in the lithosphere, and in part transient support by existing stresses.

#### OSCILLATIONS ABOUT MEAN SEA-LEVEL

Oscillations due to the westward lag of tidal bulges of water and of lithosphere as the earth turns below the attracting moon and sun, and as the distance of these bodies vary with perigee and apogee and perihelion and aphelion, result in semi-diurnal, semi-lunar, and semi-annual tides. Water behaves as a liquid for all of these, while for the lithosphere only elastic yield is observed for times up to several months, some non-elastic yield is detectable for the annual and Chandler wobbles, largely non-elastic yield for the nutation (18.6 years) and wholly fluidal for the axial precession. As the moon, which at present has four times the tidal effect of the sun, was progressively closer in the past, tidal oscillation must have been much greater. Small short-period local changes are caused by migration of air pressure cells, by major storms, winds and sustained prevailing winds. Episodic seismic sea-waves with periods of some tens of minutes can cause rises of 100 m or more, and as they transport boats some kilometres inland, they could leave behind evidence of marine provenance in coastal sediments which have never been below sea-level. However such great waves

only occur when the oceanic bathymetry (down to greatest depths) have salients to focus the wave on to the salient, and it is only along such shores that alertness for such cause is necessary.

#### TECTONIC MOVEMENTS

Migration of the geoidal rises and depressions described above (if real) may cause systematic regional oscillations of sea-level. In addition elevation or depression of individual regions relative to the geoid may be due to change of load on the lithosphere or change of temperature gradient.

Reduction of load may be due to erosion, melting of glaciers, change from humid to arid conditions, and evaporation of a sequestered lake or sea. Increase of load may be due to sedimentation or volcanic flows, or to loading due to lateral spreading from rising orogenic belts. Increase in geothermal gradient causes volume changes hence rise of lithosphere surface without change in load. At moderate depths the volume change is due to thermal expansion. At greater depths extending far into the mantle and even to the core, expansion is due to paramorphic phase changes. Phase changes to denser or less dense crystal lattices are governed by temperature and pressure. Increase of temperatures under constant overburden leads to expansion, which can be substantial.

Departures (indicated by gravity anomalies) may be induced and sustained by near-horizontal



pressures or tensions, but not for times geologically long, because all such forces relax exponentially with time. Departures may also be sustained in dynamic equilibrium. When the plug is pulled from a full bath and water starts to drain, the statically level surface is depressed over the outlet (eventually to deepen to a vortex); the volume of the depression is such that the weight of water missing is equal to the sum of the vertical components of the viscous drag in the water. Similarly if convection really occurs below the lithosphere, a surface depression would be sustained dynamically above the downward flow, and a surface rise above upward limbs.

### CAPACITY OF OCEAN BASINS

The total capacity of the ocean basins below the geoid may be affected by changes either in area or mean depths below the geoid. With earth-models which assume constant earth radius, the total area is a minor variable, because old oceanic floor is assumed to be removed by subduction *pari passu*, with creation of new crusts at mid ocean ridges, but with earth models assuming earth expansion, the area is a major variable, as almost all existing ocean floors have grown since the Palaeozoic, which (without subduction) means gross increase in area.

Depths of oceans are affected by (a) peneplanation of the lands with transfer of denudation products to the sea, (b) change of geothermal gradient, leading to paramorphic phase changes in the lithosphere and mantle. New crust at spreading ridges is 2 km deep or less. Young ocean basins are only 2 or 3 km deep, but as the lithosphere below them cools the moho boundary rises as 6 to 7 km-per-second material suffers paramorphic recrystallization to 8 km-per-second material, and the depth of the basin deepens through 4 km to nearly 5 km in old basins, (c) continental spreading as isostatic equilibrium moves slowly towards hydrostatic equilibrium. The relaxation time for isostatic disequilibrium of continental dimensions is of the order of one thousand years, whereas the relaxation time of departures from hydrostatic equilibrium is of the order of one thousand million years. To attain hydrostatic equilibrium all continents would have to spread to form an entire layer over the whole earth. As Lester King pointed out Pangaea when reassembled has a gross lensoid shape attributable to this process, indicating detectable hydrostatic spreading of continents on a time scale of  $10^9$  years, but none significant in  $10^8$  years.

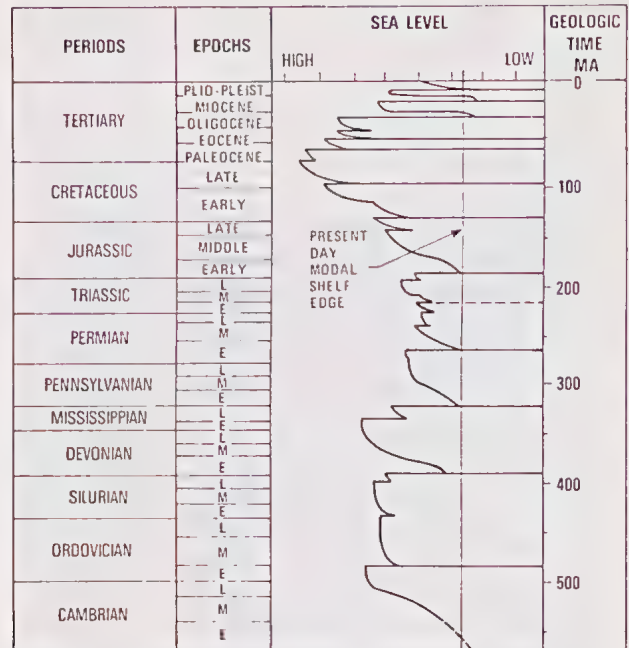


FIG. 2—Global super cycles of sea-level. (From Vail & Mitchum 1977)

### VOLUME OF SEAWATER

The total volume of seawater may be affected by (a) accretion of juvenile water from the deep interior, (b) variation of the column of seawater temporarily sequestered in terrestrial ice, the atmosphere, biosphere, or in the hydration of rocks, or (c) loss from the planet.

So far as the planet as a whole is concerned it becomes a matter of the hydrogen budget. We continually gain protons from the solar wind, and we also lose excited hydrogen to space. The relative balance is not currently known, and could have been different in the past. The total water and the variation of water held in the atmosphere and biosphere are both trivial, and could not account for any significant sea-level change. Sub-aerial weathering of rock such as basalt involves the hydration of every ion present, with considerable change of volume. Submarine weathering is volumetrically insignificant, water volume loss more or less balancing rock volume increase. Total return to the sea of all water in hydrated minerals on land would raise the sea-level by a few decimetres, but changes of sea-level due to variation to terrestrial hydration can only be trivial.

Total evaporation of a sequestered sea could be significant. For example, Donovan & Jones (1979) estimated that the Miocene evaporation of the Mediterranean Sea could have raised the general



level of the oceans by 12 m. As extensive salt deposits are known from various geological formations, desiccation could have been a cause of sea-level fluctuations of this order. If the earth radius was less during those earlier evaporation periods, the change of sea-level could have been substantially greater.

Concerning glaciation, icebergs, sea ice and floating ice shelves are irrelevant because the mass of water displaced equals the mass of the ice, so melting produces no change of sea-level. Even ice-sheets resting on sediments below sea-level can be largely omitted, because they are supported by the hydraulic uplift pressure of the groundwater seepage below them. Only land ice is relevant, but even here the effect on sea-level is only about one-third of that of the addition to the oceans of the volume of water from melted land ice, because the weight of this ice is transferred from the continent to lithosphere under the oceans. In relation to a reference continent, the ocean floor generally depresses under its increased water load, and the deglaciated continent rises owing to its loss of ice load.

## A NEW ERA FOR EUSTATISM

From time to time a new concept or new technology triggers a rapid advance in a field of science which then gradually settles down again to a more normal slow growth. Eustatism has experienced such a leap forward during the last decade. Capability to discover and produce oil and gas at sea led to vast investment by all major oil companies, and every shelf and slope in the world has been probed by magnetometer, seismic reflection, and calibrating drills. Rapid development in seismic instrumentation and analysis has opened a cornucopia of new information about offshore sediments around the world stretching back far into the Mesozoic. The recent special volume of the American Association of Petroleum Geologists edited by Vail and Mitchum (1977) on seismic stratigraphy and global sea-level changes has opened a new era in eustatic studies.

Individual seismic reflectors (dated by drill-cores) are traced from marine deposits into coastal deposits and finally to the point of onlap against older sequences. Vail and his co-authors, using coastal onlap, top lap, and other stratigraphic criteria, recognize cycles of relative rise, stillstand, and fall of sea-level. They correlated these cycles within a region, and, comparing results from several continents, found that most of the regional cycles exist on a global scale. Anomalies in the

curve for one region compared with the global curve identify local tectonic movements. This epochal work has placed several constraints on the causes of eustatic movements.

Hitherto, glacial cycles have been favoured as the prime cause of eustatism. Certainly the effect of waxing and waning of ice sheets is real. However the new work has established that the magnitude of oscillation of sea-level persists through glacial and non-glacial periods alike (Fig. 2). There are distinct frequencies of cycles. The super-cycles run for  $10^8$  years. Within those are major cycles of the order of  $10^7$  years, made up of shorter pulses of less than  $10^6$  years, which are clear in the drill cores but harder to identify and trace with present seismic technology. The global curves are empirical, with no pre-conceived cause. Quite clearly the principal cause of eustatic changes is not glacial.

Vail and his co-authors also found that the oscillations are markedly skewed. "One cycle of relative rise and fall of sea-level typically consists of a slow gradual relative rise, a period of stillstand and a rapid relative fall of sea-level. In detail the gradual rise consists of a number of smaller scale, rapid rises, separated by stillstands with no significant falls."

## CAUSE OF EUSTATIC CYCLES

What then is the cause of sea-level cycles, and of their skewed form? The literature generally has not given a satisfactory answer. Indeed Donovan & Jones (1979) go so far as to doubt the new data, because they cannot see a mechanism! I discussed this question in my book on the expanding earth, before the publication of the new data (Carey 1976):

"The keynote of William Rubey's masterly presidential address to the Geological Society of America (Rubey 1951) was that the whole of the waters of the oceans had been exhaled from the interior of the earth, not as a primordial process, but slowly, progressively, continuously, throughout geological time." . . .

"As the generation of the ocean floors depends fundamentally on the same process as the outgassing of juvenile water it would be expected that the volume of sea water and the capacity of the ocean basins both increased in a related way. But not necessarily in phase. Several variables are involved, some with feedbacks and time-delays. There should be times when the capacity of the ocean basins increased more rapidly than the total volume of sea water, and vice versa. The former

would result in general emergence and regression of the sea from the lands, the latter a transgression of the seas over the lowlands. This could happen on the gross scale of the order of whole geological periods, on epoch scale, and on progressively smaller scales to as short as a few years." . . .

"Secular variation of the temperature gradient in the mantle is another factor in this equation. When isotherms rise under a continent or megacontinent like Pangaea the depths of all phase transitions, from more dense to less dense paramorphs, descends to greater depths, and the surface bulges like rising dough, and there is general regression. Likewise as the mantle below a new ocean basin slowly loses its excess heat so that the isotherms retreat inwards, the phase transitions ascend so the floor of the basin sinks to greater depths. This increases the capacity of the basin, resulting in regression."

Skewed cycles commonly express repeating episodic events followed by exponential decay or relaxation. The time scales suggest that the long super cycles of more than a hundred million years relate to a core-mantle process. I suspect that the relatively episodic process is the increase in area of the ocean basins. The peri-continental spreading ridges (mis-named midocean ridges) divide the earth's surface into growing blocks on the same scale as the earth's primary heterogeneity of core and mantle (a few thousand km), and imply a thermal relaxation time of a few hundred million years. As orogenesis in my view is a diapiric phenomenon like the spreading ridges, the super cycles correlate with the major orogenic cycles. The shorter cycles may be primarily thermal and within the lithosphere, as the paramorphic moho boundary migrates up and down within the

oceanic lithosphere in response to changes in thermal gradient induced by pulsed vulcanism.

#### A GLOBAL EUSTATIC CHRONOLOGY

The global curves will certainly be refined to precision within the near future. Then packets of sediments will be able to be correlated with certainty between regions and between distant continents. Within these packets, current seismic correlation cannot focus more sharply than a few million years, about equal to the best fossil and radioactive correlations. However the two latter have this imprecision at the boundaries of the packets as well as within, whereas the seismic stratigraphic correlation recognizes the bounding surface quite precisely. Hence the prospect that the finer oscillations seen in bore cores may be correlated absolutely between continents, and confirmed by their running signature, just as Trendall has done so brilliantly over hundreds of kilometres with the microbands in the Pilbara banded-iron formations.

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## VICTORIAN COASTAL GEOMORPHOLOGY

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**ABSTRACT:** The geomorphology of the Victorian coast is reviewed in terms of the geological background, the processes at work in the shore and nearshore zones, and the effects of late Quaternary sea level changes. Cliffs and shore platforms, beaches and associated features, and inlets, estuaries and lagoons are each considered in relation to the processes that have shaped them, and attention is given to key problems, notably the need to quantify coastal processes, to establish more precisely the sequence of Holocene sea level changes relative to the land margin (in particular the question of a higher Holocene sea level episode), to elucidate the processes, particularly induration, that have contributed to the shaping of shore platforms, and to establish the origin and mode of delivery of sandy sediments to the present coast.

### INTRODUCTION

The study of coastal geomorphology in Victoria has evolved from geological accounts of coastal regions, many of which included descriptions of coastal features. Notable contributions came from Baker (1943, 1944, 1950, 1958) on the cliffed coasts of the Port Campbell district, Boutakoff (1963) on the Portland area, Edwards (1942, 1945, 1962) on San Remo, Phillip Island and the Lorne district, Jenkin (1968) on south-east Gippsland, and Keble (1950) on the Mornington Peninsula. Inevitably, some of the geomorphological material in these reports is outdated in terms of modern concepts, but much useful information has been summarised in the *Regional Guide to Victorian Geology* (McAndrew & Marsden 1973) and the *Geology of Victoria* (Douglas & Ferguson 1976).

More specific accounts of geomorphological features on the Victorian coast have been published by Gill, who in the Port Fairy-Warrnambool district (Gill 1967a) and elsewhere has endeavoured to trace the sequence of late Quaternary changes of sea level and the responses of coastal landforms to these changes. There have been discussions of the evolution of shore platforms (Jutson 1940, 1948, 1949a, b, 1950, 1954; Hills 1949, 1971, 1972; Edwards 1951; Gill 1967b, 1972a, b), and investigations of the nature and origin of beach sediments (Baker 1945; Beasley 1957, 1969, 1971, 1972; Bird 1970; Gell 1978) and related dune systems (Coulson 1940; Coutts 1967;

Whincup 1944). Sectors that have received attention include Port Phillip (Hills 1940, Keble 1946, Bowler 1966), Western Port (Jenkin 1962, Marsden & Mallett 1975, Bird & Barson 1975), and the Gippsland Lakes (Bird 1978).

The literature on the coastal geomorphology of Victoria is thus substantial, this being among the more intensively documented sectors of the world's coastline; yet there is still much work to be done. The emphasis so far has been on the interpretation of coastal landforms in terms of hypotheses of sea level change, deduced patterns of sediment movement, and inferred processes of weathering, erosion and deposition. Much more data is needed on the regimes of waves, tides and currents in Victorian coastal waters (including estuary and lagoon systems); on the physical, chemical and biological processes at work on rocky shores; on the quantities of sediment moving onshore, offshore and alongshore; and on the effects of local climate, especially temperature, rainfall, and wind action, on the evolution of coastal dunes and their stabilisation by vegetation. Nevertheless, the broad relationships between coastal landforms and the processes at work on them have been described, and it will be useful to summarise these and discuss some of the problems that require further consideration.

The landforms of the Victorian coast (Fig. 1) include a variety of geomorphological features, ranging from the precipitous limestone cliffs of Port Campbell and the steep granitic slopes of



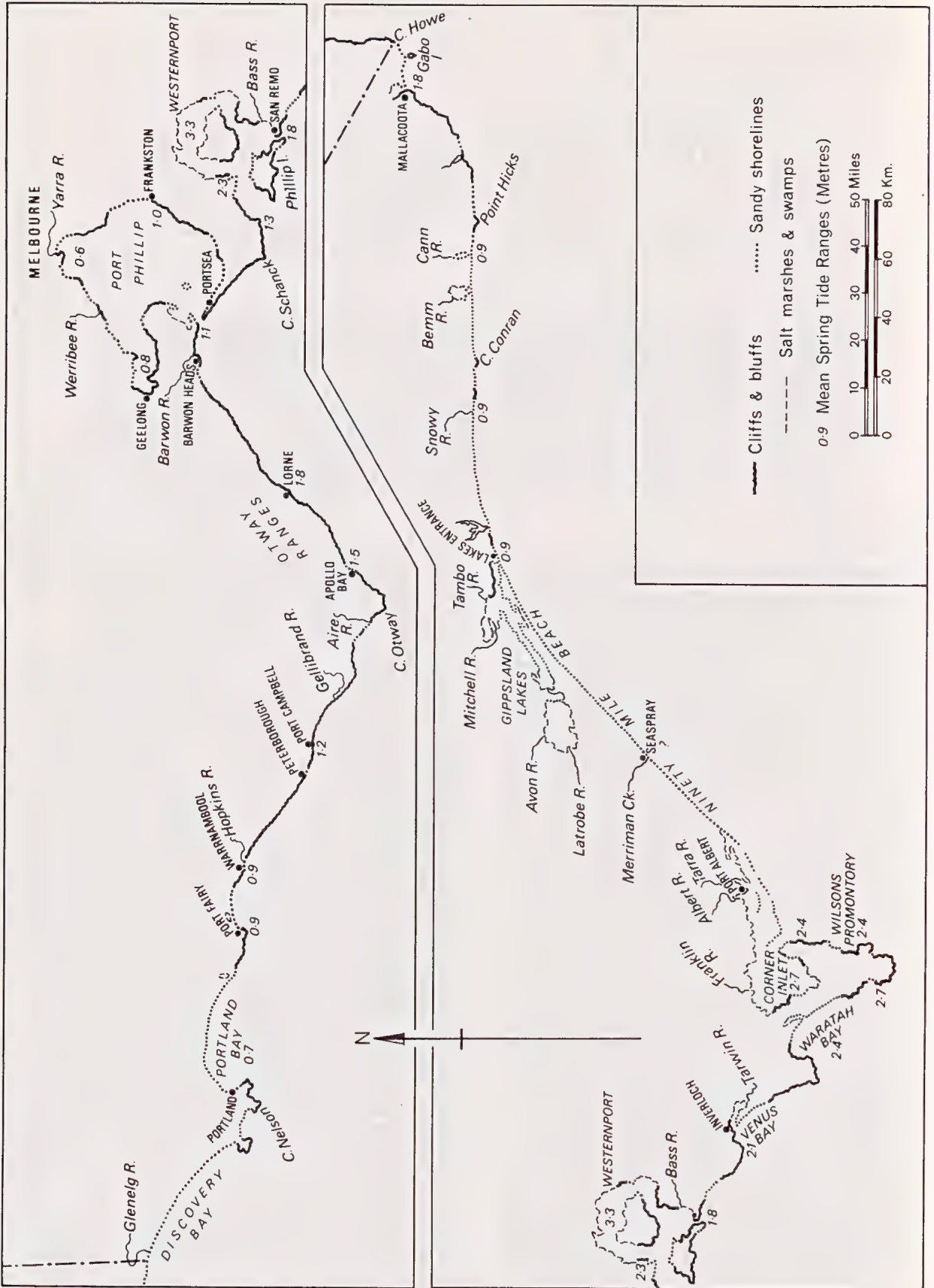


Fig. 1 — Predominant coastal landforms of Victoria

Wilson's Promontory to the long sandy surf beaches of the Gippsland coast and the low-lying mangrove-fringed salt marshes on the shores of Western Port and Corner Inlet (Bird 1977a). This diversity is related partly to geological factors and partly to contrasts in coastal processes, particularly wave action, which is much stronger on the outer, oceanic coastline than in the more sheltered inlets and embayments.

## GEOLOGICAL BACKGROUND

The coastal outlines of Victoria have been much influenced by the uplift of the Otway Ranges, the Mornington Peninsula, and the South Gippsland Highlands, and the subsidence of the Western District, the Port Phillip and Western Port sunkenlands, the Corner Inlet depression, and the structural trough that underlies the Latrobe Valley and extends beneath the Gippsland Lakes to the east. Wilson's Promontory stands out as a much-dissected intrusion of Devonian granite to the south of the Corner Inlet depression, and in the far east of the state the coastline truncates the Palaeozoic formations of the Eastern Highlands of Australia, which here show a north-south trend in the folding and faulting of the rocks and the pattern of granitic intrusions (Fig. 2).

Table 1 shows the geological formations exposed on the coast. The oldest are Cambrian greenstones, which outcrop in cliffs near Cape Liptrap, in the core of one of the anticlinal axes of the uplifted South Gippsland Highlands. Cretaceous formations are exposed in cliffed headlands between Inverloch and San Remo, and on the steep coast of the Otway Ranges, where they are flanked to east and west by outcrops of Tertiary sediments, which also extend to the shores of Port Phillip and Western Port. Older Volcanics (Eocene to Miocene) emerge on the southern coast of Mornington Peninsula and dominate the shores of Phillip Island, while Newer Volcanics (Plio-Pleistocene) border the western shores of Port Phillip Bay and outcrop on the coast of the Western District at Portland and Port Fairy. Quaternary dune formations are mainly calcareous west of Wilson's Promontory, including the partially lithified dune calcarenites of the Nepean Peninsula and the Warrnambool coast, and quartzose to the east, where they include the multiple barrier formations of the East Gippsland coast. Finally, Holocene shore sediments, mainly sand and mud, are extensive within Western Port and Corner Inlet.

## COASTAL PROCESSES

There are marked variations in the nature and intensity of processes at work along the Victorian coast. Much of the outer coastline is exposed to ocean swell derived from distant storm activity in the Southern Ocean. A prevailing south-westerly swell, with wave periods of 12 to 16 seconds, moves in through the western approaches to Bass Strait to break upon the shoreline west of Wilson's Promontory. In the eastern part of Bass Strait this swell mingles with a generally weaker south to south-easterly swell which has been transmitted through the sea east of Tasmania, and which moves in towards the Ninety Mile Beach and the predominantly sandy shoreline eastward to Cape Howe (Fig. 3).

The most vigorous storm waves in coastal waters are those generated by south-westerly gales, which break heavily on shores that face this direction, notably on the Portland promontory, the coast between Warrnambool and Cape Otway, and the headlands at Cape Schanck and Cape Liptrap. These are classified as 'high wave energy' sectors (Plate 1). They show bold, eroding cliffs and long sweeping sandy surf beaches which occupy curved embayments, the shape of which is determined by patterns of refracted ocean waves. Occasionally very large waves break against the high cliffs of the Port Campbell coast. Baker (1934) showed how storm waves at Broken Head, near Port Campbell, attain heights of up to 30 m above sea level: the cliff-top bench is awash as they break, then water pours back down the cliff face. The extreme vigour of wave attack on this coast is related to the fact that the adjacent shelf is narrow and relatively steeply shelving (Fig. 4); farther east, as the shelf widens, there is some reduction in the energy of waves reaching the shoreline, but it is still sufficient to produce heavy breakers on rocky shores, and the large 'surfing' waves that move in to Bell's Beach near Torquay, Gunnamatta, and Woolamai Beach on Phillip Island.

In the lee of headlands, and on the eastern shores of Wilson's Promontory, the prevailing south-westerly waves are weakened by refraction, and waves produced by the less frequent easterly winds, which blow mainly during the summer, are less vigorous. Consequently, these are 'moderate wave energy' sectors, with cliffing less pronounced, and coastal slopes in places vegetated down almost to high tide level.

Port Phillip, Western Port and Corner Inlet are penetrated only to a limited extent by ocean swell. Their shores are subject to waves generated by



TABLE I.  
SUMMARY OF VICTORIAN COASTAL GEOLOGY

<i>Era</i>	<i>Period</i>	<i>Age m.yr.</i>	<i>Epoch</i>	<i>Coastal Geology</i>
CAINOZOIC	Quaternary		Holocene	Modern beaches, dunes, salt marshes Swamp peats, especially Western Port Tower Hill tuff Tyrendarra lava flow
			Pleistocene	Dune calcarenites mainly west of Wilson's Promontory Quartzose sands of Gippsland coast Quartzose sands of Port Phillip and Western Port Silty clays of the Bellarine Peninsula Older alluvium in bays and inlets Newer Basalt of Portland area and the Western District, extending south of Geelong and to the west coast of Port Phillip
	Tertiary	2		
			Pliocene	Ferruginous sands and sandstones (e.g. Baxter Sandstone) around Port Phillip and Western Port, and in East Gippsland Maretimo clays and early Newer Basalts in the Portland district
		7		
			Miocene	Balcombe Clay on the Mornington Peninsula Fyansford Clay and Curlewis Limestone on the Bellarine Peninsula Clays and sandy limestones at Torquay Clays near Princetown overlain by the Port Campbell Limestone, extending west to the Warrnambool district Portland Limestone Final flows of the Older Basalt
		26		
			Oligocene	Point Addis Formation, passing laterally from limestone to clay near Torquay, and resting on the Angahook Formation, which shows lateral transition from sand and clay at Anglesea through volcanic rocks at Airey's Inlet to limestones near Torquay Some Older Basalt
		38		
			Eocene	Anglesea Sand; with organic sandy beds at Demon's Bluff Major Older Basalt flows of south-east Mornington Peninsula and Phillip Island
		54		
			Palaeocene	Eastern View Coal Measures at and west of Anglesea Grits, sandstones and clays between Moonlight Head and the mouth of the Gellibrand River
	Cretaceous	65		
				Sandstones (arkoses) and mudstones of Otways and South Gippsland (San Remo; Kilcunda; Cape Paterson-Anderson's Inlet), with minor outcrops in Port Phillip and Western Port
		136		

MESOZOIC	Jurassic			
	Triassic	195		
	Permian	225		Not represented
	Carboniferous	280		
PALAEOZOIC		345		
	Devonian			Intruded granites of Wilson's Promontory, Cape Woolamai, East Gippland, and granodiorites of the Mornington Peninsula Liptrap Formation at Cape Liptrap, and Bell Point and Waratah Limestones at Walkerville
		395		
	Silurian			Sandstone Island and Golden Point, Western Port
		440		
	Ordovician			Limestones and shales near Walkerville Shales and sandstones of the East Gippsland capes
		500		
	Cambrian			Greenstones near Cape Liptrap
PRE-CAMBRIAN		570		
				Not represented

winds blowing over short fetches within these bays, waves with typical periods of between 5 and 8 seconds. The prevalence of westerly winds produces stronger wave action on the eastern shores, which are in places subject to moderate wave energy, sufficient to have cut cliffs in sandstones and weathered granite and basaltic rocks (Plate 2). The more sheltered western shores have low wave energy conditions, with a more subdued topography, only limited cliffing and extensive development of depositional features, including sandy beaches, cusps, and spits, as well as salt marsh and mangrove fringes. The bay shorelines thus have a more intricate configuration than that of the high-energy oceanic coasts.

Other variations in coastal morphology are related to contrasts in tide range (Easton 1970). Tides in Victorian coastal waters are the outcome of westward movements through Bass Strait and around the southern and western shores of Tasmania. Mean spring tide ranges vary from less than a metre on the coasts of East Gippsland and the Western District to more than 2 m around Wilson's Promontory. At Point Lonsdale the mean spring tide range is 1.1 m, but it diminishes inside Port Phillip because the narrow gap between Heads impedes the inflow and outflow of tidal water. By contrast, tide ranges are augmented in Western Port, rising from 1.3 m at

Flinders to 2.3 m at Stony Point and over 3 m north of French Island (Fig. 1). Little is known of the tides in and around Corner Inlet.

The extent of the inter-tidal zone is related partly to tide range and partly to the transverse gradient of the shore. On the ocean coast the area exposed at low tide averages 50 m in width, some sectors being rocky and others sandy. Within Port Phillip the inter-tidal zone (28 km<sup>2</sup>) is generally about 30 m wide, also rocky and sandy, except for some muddy areas in Swan Bay and Corio Bay. Western Port has a much larger inter-tidal area (270 km<sup>2</sup>) with broad sandy and muddy areas exposed at low tide, particularly in the northern part of the bay where the ebb divides on either side of the tidal watershed between Lang Lang and French Island (Miles 1976). In Corner Inlet and behind the sandy islands off Port Albert the inter-tidal zone has an area of about 180 km<sup>2</sup>, and in Anderson's Inlet, the estuary of Tarwin River, 16 sq. km of sand and mud flats are exposed at low tide. In all, Victoria has about 600 km<sup>2</sup> of inter-tidal land, the features of which await more detailed investigation.

Where the tidal range is small, tidal currents are weak, and have little effect on the erosion or transportation of coastal sea floor sediment, but where the range is large, and especially where the tide moves in and out of narrow straits, the



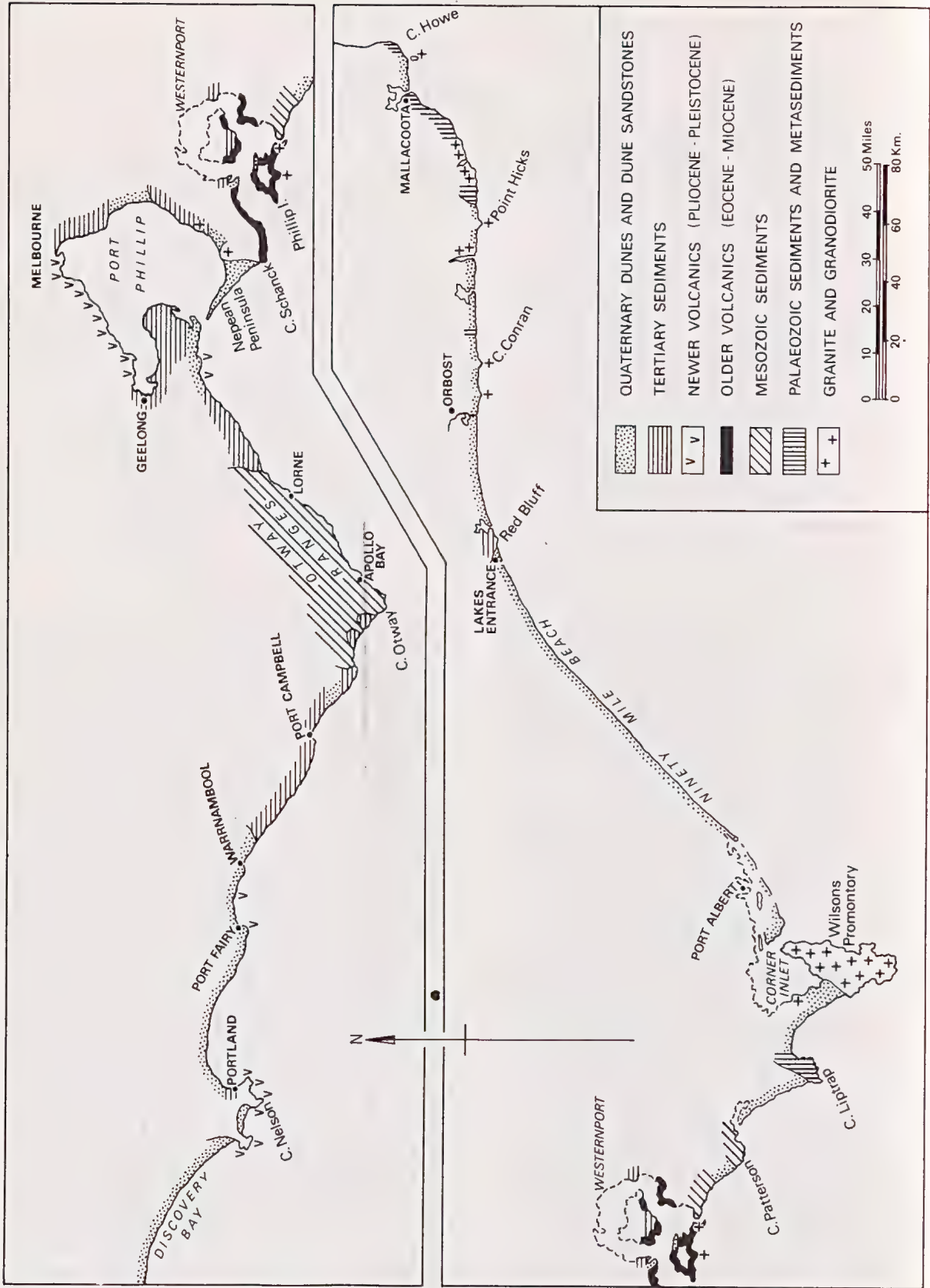


Fig. 2—Coastal geology of Victoria

associated currents may be strong enough to have direct or indirect effects on coastal morphology. Although the entrance has been widened and deepened by blasting, tidal currents through Port Phillip Heads still attain 10 to 15 km/hr (Australia Pilot, 1969), and in the shallow southern parts of Port Phillip there is a 'tidal delta' of shoals separated by diverging channels (Keble 1946). Shoal and channel topography is also found in Western Port, particularly in the north, where a tide range of more than 3 m generates strong currents as the sea rises and falls across broad intertidal mudflats. Tidal scour is strong in the narrow eastern entrance to this bay at San Remo, and tidally-scoured channels can also be seen in the sandy entrances to Anderson's Inlet, Corner Inlet, and the gaps between the sandy barrier islands off Port Albert. There are also tidal currents through the artificial entrance to the Gippsland Lakes, where the topography of the floor of Lake King shows giant ripples due to tidal scour (Bird 1978).

Tidal currents can influence shoreline features both directly, where the lateral shift of a scoured channel towards the shore leads to undercutting, or where the migration of such a channel away from the shore results in shallowing and sediment deposition, and indirectly, where deepening of nearshore water by tidal scour permits stronger wave action to attack the shore, or where nearshore tidal deposition of sediment weakens wave attack and augments shore accretion. These effects can be seen around the entrance to Corner Inlet, and alongside the channels between the sandy islands to the east (Plate 3).

Other processes influencing coastal evolution include wind action which, in addition to generating waves, acts as an agent of deflation of sand from beaches and cliff faces, and has built and shaped coastal dune formations. Apart from studies of dune orientation in relation to onshore wind resultants (Teh Tiong Sa 1973, Bird 1978), little attention has been given to the effects of variations of wind regime and wind energy along the coast, notably between sectors exposed to the prevailing westerlies and sectors that face in other directions.

### SEA LEVEL CHANGES

Considerable attention has been given to the problem of establishing the late Quaternary sequence of changes of sea level relative to land in Victoria (e.g. Gill 1961, 1971a, b, 1972c, 1973a, b, c; Gill & Hopley 1972). There is evidence that the sea stood about 7.5 m above its present level in western Victoria some 125 000 years ago, and

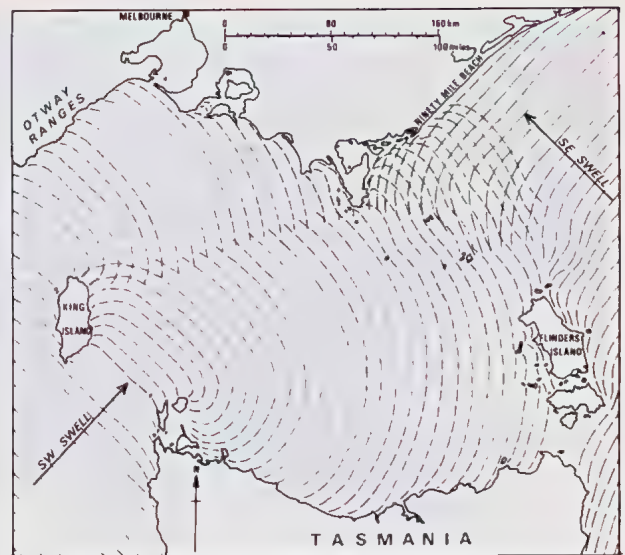


FIG. 3—Predominant ocean swell patterns in Bass Strait

about 4 m above present level 110 000 years ago (Gill & Amin 1975). There followed a long episode of low sea level correlated with the Last Glacial phase of the Pleistocene, evidence from other areas indicating that the sea fell at least 100 m, and possibly as much as 140 m below its present level 20 000 years ago. The ensuing phase of climatic amelioration and world deglaciation was marked by the Holocene marine transgression, which brought the sea up to its present level about 6 000 years ago. A number of coastal features, including emerged beaches and beach ridge systems, bluffs formed by the subaerial degradation of former sea cliffs, depositional plains that have the appearance of emerged lagoon floors, and sandy shoreline features stranded to the rear of subsequently prograded marshlands, have been taken as evidence that the sea was 2 to 3 m above its present stand between 6 000 and 4 000 years ago, and that it thereafter dropped back, yielding a 'Recent emergence'. The question of a higher Holocene sea level remains controversial, for studies on other parts of the Australian coastline, especially in New South Wales, have failed to substantiate it (e.g. Thom *et al.* 1972). Some of the emerged features on the Victorian coast could be of Pleistocene rather than Holocene age; of the order of 100 000 years old instead of less than 6 000. Alternatively the appearance of emergence could be misleading, the Holocene features having developed as the result of depositional processes with the sea at its present level. If they are emergent features they could be due to localised uplift of land during the past 6 000 years rather than a fall of sea level.





PLATE I

High wave energy coast at London Bridge, near Port Campbell (N. Rosengren, April 1976)

Attempts to correlate the evidence of former sea levels along the Victorian coast are thus complicated by the question of whether the land margin has been tectonically stable in late Quaternary times. Continuation of volcanicity into the Holocene in the Tower Hill region and the recur-

rence of earthquake activity along Selwyn's Fault on the Mornington Peninsula are among the phenomena which make the assumption of tectonic stability doubtful: Victoria has had a long history of tectonic deformation transverse to the present coastline. Moreover, there is the possi-

bility of a differential hydro-isostatic response of the shelf and coastal margin to increasing water load as the sea rose between 20 000 and 6 000 years ago. There are contrasts in the width and gradient of the shelf off the Victorian coastline (Fig. 4), and in its structural composition. There may also have been lateral variations in its resilience and hence in its response to hydro-isostatic loading. If this is the case, the sequence of sea level changes relative to the land will be different at various points along the Victorian coastline. Clearly, much more research is needed to establish sea level sequences, and as this proceeds it will be useful to map the lateral extent of the various emerged shoreline features, and to provide geomorphological explanations for their absence from intervening sectors.

### CLIFFS AND SHORE PLATFORMS

High sectors of the Victorian coast show a variety of transverse profiles, related primarily to the type and structure of outcropping rock formations and the degree of exposure to strong wave action (Hills 1971). Within granitic sectors, for example, the hard, massive granite of Wilson's Promontory shows steep rocky coasts plunging into deep water close inshore, whereas the intricately jointed granite of Cape Woolamai has been cut back into vertical cliffs behind segments of abraded shore platform, particularly on the more exposed western side, the eastern flank showing gentler coastal slopes without such platforms. In East Gippsland the granitic capes have an irregular shore topography, with only limited cliffing.

Similar variations can be traced within basalt coasts, and on sedimentary formations such as the Cretaceous sandstones and mudstones of the Otways and South Gippsland coasts (Gill 1967b, 1977), the Pleistocene dune calcarenites of the Warrnambool District (Gill 1943), Point Lonsdale (Gill 1948), and the Nepean Peninsula (Bird 1975). On some sectors, the eroding cliffs give place laterally to coastal bluffs with a soil and vegetation mantle. These are former marine cliffs that have become subaerially degraded. Some are relics of a Pleistocene coastline, as at Two Mile Bay, near Port Campbell, where the Pleistocene bluff is fronted by a low-lying coastal terrace while adjacent sectors of the coast have been cut back into vertical retreating cliffs (Baker & Gill 1957). On other sectors the bluffs appear to have been active cliffs earlier in Holocene times, and to have become subaerially degraded either as the result of

a fall of sea level relative to the land, or the deposition of beach ridges and dunes as fronting terrain which now protects them from marine attack. This sequence may be illustrated at Rickett's Point, on the north-eastern coast of Port Phillip, and on the basalt shoreline between Flinders and Somers in Western Port (Bird 1977b).

There has been considerable discussion of the mode of origin of shore platforms on the Victorian coast, and of whether their evolution required, or could be taken as indicating, a phase of higher Holocene sea level. Shore platforms show variations related to geological features and aspect. They include seaward-sloping facets which are usually ramps formed by abrasion where waves armed with sand or gravelly debris are eroding the rocky shore near the base of the cliff. There are also almost horizontal benches, terminating with a steep drop at their seaward margins. It is acknowledged, following Hills (1949), that these latter features have been shaped primarily by weathering processes, including the disintegration of rock outcrops that occurs as the result of repeated wetting by wave splash, sea spray, or rainfall, followed by drying of the rock surface. Associated with this is the process of salt crystallisation, which is difficult to distinguish from wetting-and-drying. Coastal rock formations are also subject to solution by sea water, aerated spray, rainfall and runoff, and percolating groundwater, these effects being most marked on limestones, including Pleistocene dune calcarenites. The activities of plants and animals that inhabit these rocky shores also contribute to the physical and chemical weathering of rock surfaces. In each of these ways, rock material is decomposed or disintegrated, and can be readily swept away by waves that break across the shore platform (Bird 1974).

It is evident that these processes are effective only down to a specific level, usually slightly above mean high tide level on basalts and non-calcareous sandstones and mudstones, and a little lower on limestones and dune calcarenites. A downward limit to wetting-and-drying and salt crystallisation is set by the water table, for these processes cannot operate where the rocks are permanently saturated. Similarly, solution by spray and rainfall cannot operate below low tide level, and solution by sea water at lower levels is evidently unimportant, as are the activities of the shore organisms that occupy zones below low tide level. It has been suggested that sea water is usually saturated with dissolved carbonates, and therefore incapable of further solution of limestone or dune calcarenite,





PLATE 2

Moderate wave energy coast at Black Rock Point, Port Phillip (E. C. F. Bird, October 1975)

but this hypothesis has not been examined on the Victorian coast.

The development of almost horizontal shore platforms in the transverse profiles of basalt, sandstone, mudstone, limestone and dune calcarenite coasts in Victoria can be largely explained in terms of this inhibition of shore weathering processes at and below specific intertidal levels. In addition, as Hills (1971) noted, there is evidence that shore platforms cut in dune calcarenite have become indurated by carbonate precipitation within a horizon immediately below the platform level. As a result, the outer edge of the shore platform on the ocean coasts of the Nepean Peninsula is typically a protruding slightly hardened rock. Shore platforms cut in Tertiary sandstone at Beaumaris and Mount Eliza on the coast of Port Phillip appear to have been similarly indurated, in this case by precipitation of feruginous compounds. Further investigation of the process of induration is needed: by impeding erosion it has led to the persistence of almost horizon-

tal shore platforms on the transverse profiles of coasts where erosional processes have otherwise prevailed.

#### BEACHES AND ASSOCIATED FEATURES

During late Quaternary times, large quantities of sand have been deposited to form beaches, spits, barriers and dunes on the Victorian coast. Deposition has been most extensive in Discovery Bay, Portland Bay, and Port Fairy Bay; between Torquay and Cape Schanck; near Cape Woolamai on Phillip Island; between Kilcunda and Cape Patterson; in Venus Bay; and along the Gippsland coast east of Wilson's Promontory (Fig. 1). As has been mentioned, the sand deposits west of Wilson's Promontory are predominantly calcareous, while those to the east are largely quartzose. Sand deposition has also taken place locally on the shorelines of Port Phillip, Western Port and Corner Inlet,

Sources of beach material include sand and gravel eroded from cliffs and foreshore outcrops and deposited on adjacent beaches, sandy sediment brought down from the hinterland by rivers and redistributed from river mouths, and sand carried in from the sea floor by shoreward drifting (Bird 1980). The first of these is readily demonstrable along actively-cliffed sectors of the Victorian coast, where beaches in the vicinity of cliffs of Tertiary sandstone, as on the eastern shores of Port Phillip, or cliffs cut in dune calcarenite, as in the Warrnambool district, certainly include material derived from these sources. In north-eastern Port Phillip between Brighton

and Mentone the depletion of sandy beaches in recent years has followed the artificial stabilisation of formerly eroding cliffs that maintained a sand supply (Bird 1970). Beach gravels occur locally near rock outcrops which are weathering into fragments that become worn into cobbles and pebbles by wave action (Bird 1972). Shelly beaches are also found locally, either near rocky shores or reefs which provide a habitat for shell fauna, as in Bridgewater Bay, or adjacent to biologically rich estuarine or shallow marine environments, as in parts of Western Port. On the west coast of Port Phillip shelly beaches occur where other sources of beach material are sparse on a low-lying shore that

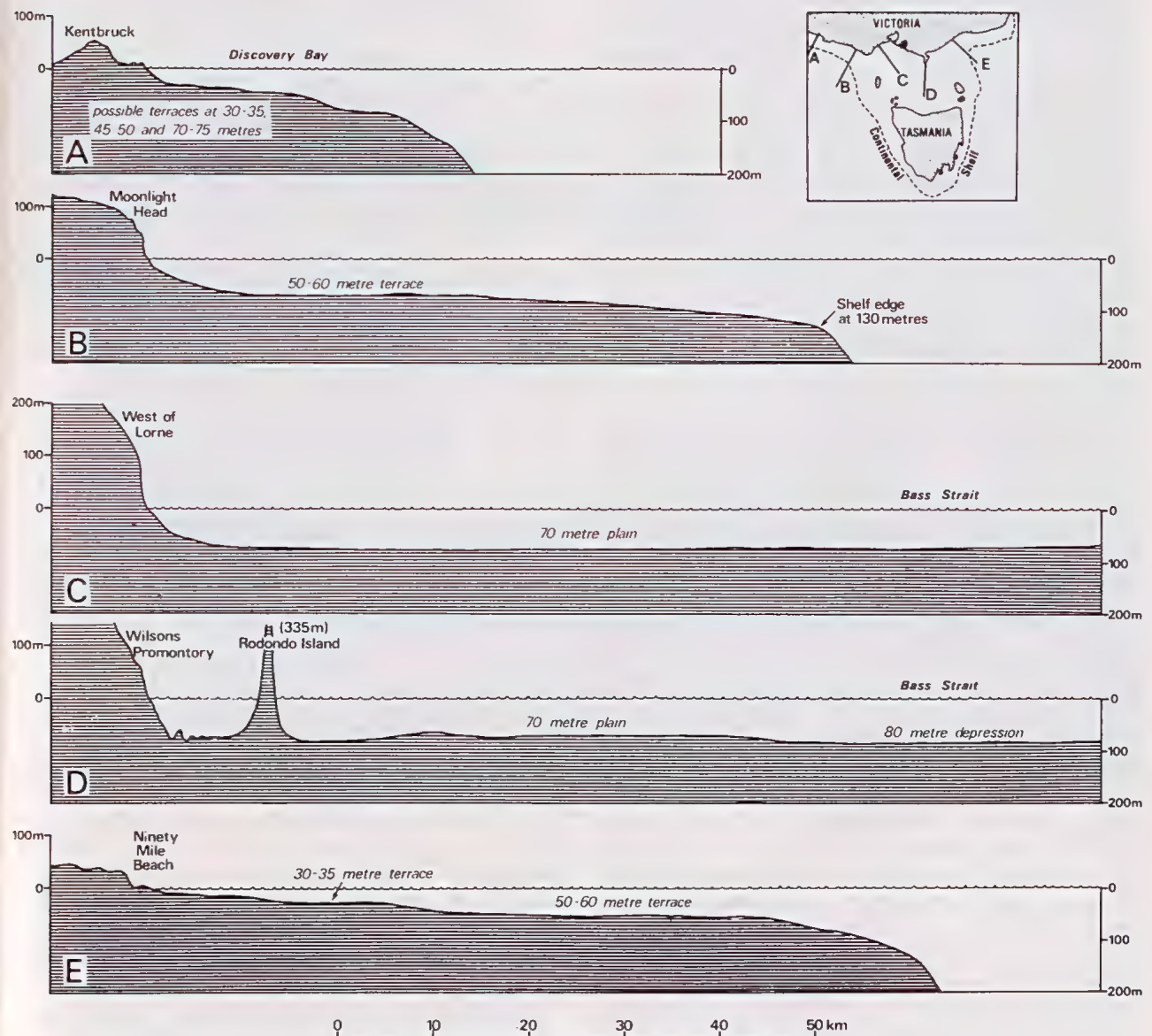


FIG. 4—Profiles of the continental shelf off Victoria



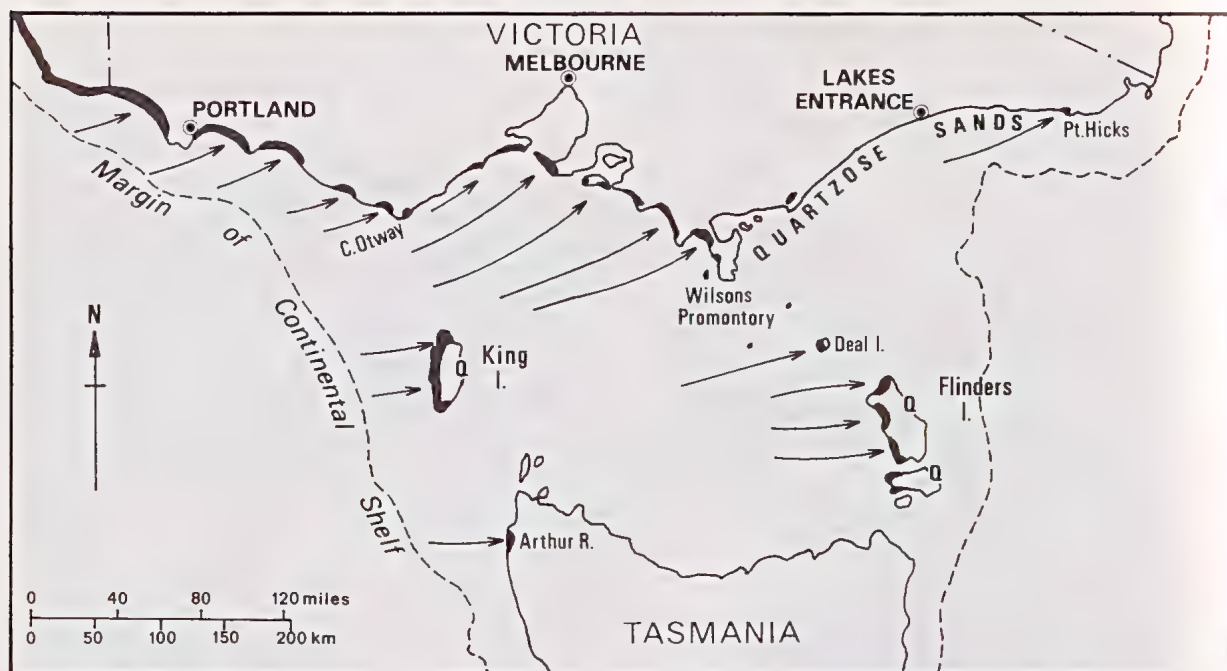


FIG. 5—Flow paths of biogenic shelf sand to calcareous beaches (shown in black)

borders weathered basaltic terrain (Gell 1978).

Sand from rivers has made only minor contributions to Victorian beach systems, because most of the rivers drain into estuarine lagoons which intercept sandy sediment before it reaches the sea. Thus sand from the Mitchell and Avon Rivers is being deposited in the Gippsland Lakes rather than on the Ninety Mile Beach. Some fluvial sand is nevertheless carried into the sea by the Snowy River during episodes of flooding, deposition by this river having largely filled the estuarine lagoons that formerly existed at its mouth. In the winter floods of 1978 sand swept out of the mouth of Merriman's Creek was subsequently added to the adjacent Ninety Mile Beach.

The development of the sandy barrier behind the Ninety Mile Beach on the Gippsland coast can only be explained by shoreward drifting of sand from the sea floor. Although it incorporates fragments of Pleistocene barriers, this outer barrier is essentially a Holocene formation, initiated when the marine transgression brought the sea to its present level, and subsequently prograded. The deposited sand cannot have come either from cliff erosion, for the only cliffed sector is the minor promontory of Red Bluff at the eastern end of the Ninety Mile Beach, or from fluvial supply, since the hinterland rivers drain into lagoons landward of the barrier. Instead, sand has moved in from the sea floor, where relics of Pleistocene beaches,

barriers and dunes stranded during the preceding phase of falling sea level, together with sediment deposited on the emerged sea floor by rivers and wind action, and sandy material produced by the weathering of shelf outcrops, were re-worked, collected, and carried shoreward by wave action during the Holocene marine transgression, and deposited to prograde the barrier shoreline (with successive beach and dune ridges) after that transgression came to an end. The process of landward sweeping would have been aided by stillstands or minor episodes of emergence as the Holocene transgression proceeded, and an emergence following a higher Holocene sea level episode would help to explain the subsequent progradation of the outer barrier; but this is not essential. Given an abundant sand supply, the barrier shoreline could have prograded with the sea at its present level, and parts of the barrier islands off Port Albert are indeed still prograding as waves move sand in from shoals on the adjacent sea floor. Along the Ninety Mile Beach, however, this progradation has come to an end, and in recent decades the shoreline has been receding as sand is lost offshore and alongshore. Erosion on sandy shorelines in Victoria has been discussed in a previous paper (Bird 1980).

Shoreward transportation of sand has also contributed beach material to other parts of the Victorian coast, the quantities delivered being related



PLATE 3

Tidal inlets between sandy barrier islands off Port Albert in South Gippsland (N. Rosengren, March 1976)

to the pre-existing topography and sediment mantle of the adjacent shelf. The relatively steep narrow shelf off the Western District would be unlikely to have provided as abundant a sand supply as a broad and gentle shelf of the kind off the Ninety Mile Beach (Fig. 4), so that the pattern of

Holocene deposition in the Port Fairy District has differed from that of the Gippsland coast. Each coastal sector has a 'shelf catchment' determining the extent to which sediment has been carried on-shore. The dichotomy between calcareous sands on the coast west of Wilson's Promontory and



quartzose sands to the east can be explained in terms of derivation from contrasted sea floor catchments during successive sea level oscillations, the largely biogenic calcareous sands having come from shelf areas to the west, where the sediment mantle is calcareous (Fig. 5), while the quartzose sands came from the granitic province associated with the shelf to the east.

The pattern of deposition of sand carried shoreward depends also on coastal configuration in relation to predominant wave regimes. Beach sand drifts along the shore where waves arrive at an angle, and accumulates on sectors where the waves move in to fit the shoreline. The pattern of sand deposition in Portland and Waratah Bays is the outcome of this. Alternatively, sand drifting into the mouths of inlets and embayments may accumulate in bordering spit formations, such as Sandy Point and Observation Point in Western Port.

Beach drifting continues, but although patterns of coastal sediment flow have been traced (Baker 1956, Bird 1972, Tan 1970) little is known of the quantities of beach material moved or the rate at which longshore transportation proceeds. More quantitative studies are required of the kind devised by Gill (1978) who sought to relate volumes of cliff retreat to volumes of sand deposition on the Port Fairy coast, and Riedel & Fidge (1977) who attempted to calculate the rate of movement of sand along the shore from Point Lonsdale to the compound spit formation at Swan Island in the south-west of Port Phillip.

Where dune topography has developed behind sandy beaches it consists either of successions of foredunes parallel to the shoreline and largely held in place by a vegetation cover, or more complex transgressive dunes, including blowouts, parabolic dunes, and sand lobes that have moved inland, some now fixed by vegetation, others unvegetated and mobile (Plate 4). Parallel foredunes are best displayed behind the Ninety Mile Beach and towards the more sheltered western ends of embayments such as Portland and Waratah Bays. On the more exposed parts of these embayments, and along the coast east of the Ninety Mile Beach, parallel foredunes give place laterally to more irregular transgressive dune formations, many of which are active, driven by the prevailing south-westerly winds inland or across promontories. Burning, grazing and trampling of dune vegetation has undoubtedly initiated erosion and mobilised formerly stable dunes during the two centuries of European occupation, but in some cases instability may have originated earlier, as the

outcome of burning of vegetation by aboriginal tribes. Older parabolic dunes now stabilised by vegetation indicate still earlier phases of natural instability, when the vegetation cover was weakened by aridity or natural bushfires, when the seaward margins were undercut by storm waves or rising seas, or when onshore winds were stronger than they are now. Where the sands are calcareous, secondary carbonate cementation has preserved overlapping Pleistocene dune formations, indicative of a long history of alternating natural stability and instability, as dune calcarenites, the seaward margins of which have been cut back as rugged cliffs on the Nepean ocean coast. Quartzose dune sands do not become lithified in this way, and the Pleistocene coastal dune topography of East Gippsland has been more readily eroded and redistributed than the dune calcarenites of equivalent age farther west.

Rates of movement of mobile dunes measured behind Discovery Bay have been up to 2 m per year, and in East Gippsland have been up to 13 m per year (Rosengren 1978), much of the advance occurring during episodes of strong wind action, especially in winter. More detailed investigations are in progress which should elucidate patterns of sand movement on mobile dunes in relation to local wind action and the effects of wetting of surface sand by rainfall, which is thought to inhibit deflation. Vegetation which traps and stabilises dune sand on the Victorian coast includes the grasses *Spinifex hirsutus*, *Festuca littoralis*, and the introduced *Ammophila arenaria*, as well as such shrubs as *Cakile maritima*. Attempts to stabilise dunes by planting such vegetation have been more successful in wet years, when rainfall has stimulated the growth and spread of these grasses and shrubs.

## INLETS, ESTUARIES AND LAGOONS

The Holocene marine transgression established a number of valley-mouth inlets, as well as larger embayments such as Port Phillip, Western Port, and Corner Inlet, which owe their outlines partly to tectonic movements that continued into Quaternary times. Most inlets and estuaries are encumbered by sand deposition in and around their mouths, with shallow thresholds where sand has been washed in from the sea, usually flanked by spits surmounted by dune topography (Bird 1967). Such features are seen at the entrance to Mallacoota Inlet, an intricately branched ria formed by marine submergence of the mouth of Genoa River and its tributaries. Other inlets, such



PLATE 4

Transgressive dunes on the isthmus at Cape Woolamai (N. Rosengren, March 1976)

as Lake Tyers, are subject to phases of complete enclosure when sand barriers are built up across their mouths, reopening when these are overwashed and breached during the floods that result from occasional episodes of heavy rainfall. Anderson's Inlet, at the mouth of Tarwin River, is

a funnel-shaped estuary with a sandy threshold and bordering spits, and extensive areas of intertidal sand and mudflats, partly occupied by mangrove swamps and salt marshes dominated by introduced *Spartina* species (Boston 1973).

In western Victoria the Glenelg opens into an



estuary fringed by salt marshes and bordered by ridges of calcareous sand and dune calcarenite, and there are minor estuaries at the mouths of the Surry and Fitzroy Rivers, and more extensive lagoons such as Lake Yambuk, fed by the Eumeralla and Shaw, Belfast Lough fed by the Moyne, and Curdie's Inlet. The Barwon River flows through a freshwater swamp area before entering shallow Lake Connewarre, from which a winding tidal channel, fringed by mangroves and salt marsh, leads to the sea across a sandy spit-fringed threshold at Barwon Heads. In South Gippsland, Shallow Inlet is a broad lagoon fed only by small freshwater streams, with a winding outlet across a sandy threshold.

The most complex estuarine lagoon system is the Gippsland Lakes, fed by the Latrobe, Avon, Mitchell, Nicholson and Tambo Rivers and some smaller streams, and separated from the sea by a succession of Pleistocene and Holocene barriers. Its shorelines are partly sandy and partly swamp-fringed, the fresher areas towards river mouths bordered by *Phragmites* swamp while the more brackish areas towards the artificial entrance (opened in 1889) have salt marsh. The evolution of this extensive lagoon system has been discussed by Bird (1978), and its ecology and hydrodynamics are the subject of further investigations by the Environmental Studies Section of the Ministry for Conservation.

There is a need for more detailed studies of the various inlets, estuaries and lagoons along the Victorian coast as a basis for geomorphological, hydrological and ecological comparisons, and as a means of identifying the factors that should be taken into account in devising the management of these systems as water and wetland resources with associated fisheries and wildlife, scenic values, and recreational opportunities.

## CONCLUSION

Geomorphological studies on the coast of Victoria have reached a transitional stage, the phase of description and analysis of coastal features and changes in progress giving place to more quantitative assessments of the dynamic relationships between process and form based on detailed studies of selected coastal sectors. The already substantial geomorphological literature provides a background for the selection of these sectors and the pursuit of quantitative studies.

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## EVOLUTION OF THE VICTORIAN COASTLINE

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**ABSTRACT:** The history of the Victorian coastline can be traced back to the Late Cretaceous and its evolution is closely related to the development of the Eastern Highlands. Superimposed on local and regional earth movements are glacio- and tectono-eustatic sea level fluctuations. The shore zone has migrated between the outer edge of the continental shelf and the upland front.

Former correlations and interpretations are questioned, particularly with regard to the Gippsland Lakes area, and previously unreported Quaternary marine sediments from the Peterborough coast are briefly described. Tertiary shoreline and shoreline-related features in southern Victoria are more widely represented than previously thought and provide important local physiographic control in some areas.

The Quaternary shore, except in far southwestern Victoria, did not migrate inland far beyond the present coast, implying considerable earth movement during that time.

Radiometric dating of coastal features, sedimentary facies analysis, detailed topographic surveys and a reliable global stratigraphic scale are required for the detailed elucidation of Victorian coastal history.

### INTRODUCTION

The coast is a zone of interaction between marine and terrestrial forces, the nature and intensity of which control the kinds of landforms produced and the types of deposits formed. The Late Cretaceous Victorian coast formed the inner margin of a series of partially interconnected marine basins which commenced as broad downwarps during Early Cretaceous times. However, the maximum marine incursion occurred at different times in different basins.

The basins owe their general shape directly to tectonics, but shorelines have varied throughout their history in response to changes in the relative levels of land and sea. The tectonic movements were of two kinds: broad, epeirogenic uplift and downwarping, and local movements related to sharply defined structural lineaments (Fig. 1). Earth movement was an important determinant of relative sea level, but upon this were superimposed fluctuations in the actual level of the sea itself.

Former coastal zones may be represented by erosional and depositional landforms as well as characteristic deposits. The recognition of former coastal features in Victoria is still controversial, just as the relative importance of tectonics and glacioeustasy in sea level change remains open to debate.

Current views on these points are discussed below and some possible alternative interpretations of Victorian sequences suggested.

### RETREATING SHORELINES OF THE LATER TERTIARY

The retreat of the sea from the Tertiary basins occurred in the Late Miocene to Pliocene, although some local readvances have been recorded (Abele, *et al.* 1976). In the Murray Basin the uppermost marine sediments are a sheet of silts and sands, the upper surface of which is ridged by a series of subdued to prominent, sub-parallel elongate rises (Fig. 1). The more prominent ridges were recognised by Hills (1939) who suggested that they were reflections of faulting and warping in the underlying bedrock. Subsequently, it was proposed that the ridges represented stranded coastal dunes (Blackburn 1962). Although these ridges cannot be accepted in all cases as former dunes, owing to the frequent coarseness of the sediments and the sub-aqueous nature of the bedding, it is now accepted that they represent stranded shoreline features, the precise nature of which has yet to be determined (Lawrence 1966, 1975, 1976, Bowler & Magee 1978).

ERTS imagery indicates the multiplicity of these features (Fig. 1), data which were not available to





the earlier workers. Ridges of this type are not confined to north-western Victoria. In the Otway Basin, they are also displayed on Late Tertiary sediments which survive as "windows" within the Volcanic Plains. Towards the Otway Ranges a similar parallelism appears in the deeply dissected valleys (Fig. 1). Satellite imagery indicates the possibility that the parallel interfluvial represent the sites of former shoreline features and that the streams followed the inter-ridge troughs, deeply dissecting them during subsequent uplift. The dissection observed on the upthrown blocks is lacking on adjacent lower blocks, although ridge and valley trends are maintained from one area to the other. Even though the deposits which have been preserved are fragmentary, their nature suggests shallow water, probably shore zone deposition. At least two distinct depositional environments are indicated. The coarser sediments exhibit gently seaward-dipping laminae and steeper landward-dipping beds, while the silts and clays are abundantly burrowed, suggesting turbulent and sheltered shore zone conditions respectively. These deposits are regarded as being westerly equivalents of the Moorabool Viaduct Formation, the age of which varies from Early to Late Pliocene (Abele *et al.* 1876, Douglas 1977).

The ridges are intersected by the dominant north-easterly tectonic trend, their transverse displacement on faults being clearly seen on ERTS photographs. In addition, the division between the parallel interfluvial of the deeply dissected area and the gentle ridge and swale terrain is very sharply defined by the well-established Curdie and Colac Faults. The ridge trends are straight or slightly concave towards the southwest and there is a slight change in direction between the central fault block and the blocks on either side. Within the two easterly blocks themselves, there is a change in direction of the ridges from north-north west to northwest as the sea is approached, although the trend of the innermost group of ridges is more towards the northwest and continuous across the projected continuation of the Curdie Fault. The changes in trend would be consistent with skewed tilting of the fault blocks during uplift of the land and associated retreat of the sea.

In the western part of the Port Phillip Sunkland, which occupies the eastern end of the Otway Basin, the Moorabool Viaduct Formation has a non-marine component, although its extent is not known, and the undoubted marine deposits were of shallow water origin (Bowler 1963). Some of these deposits in the Geelong area are regarded as intertidal and to have been deposited in an east-

west strait (Doust 1968), but no shoreline features as such have been identified.

On the Brighton coastal plain, on the northeast side of Port Phillip, there is a series of low parallel ridges forming the upper surface of Late Tertiary shallow water marine sediments. The ridges, once thought to be tectonic, are now accepted as being depositional features (Kenley 1967, Vandenberg 1971). It seems likely that the ridges are shore features similar to those on the Port Campbell coastal plain. In addition, there is a continuity of trend with the ridges south-east of the Beaumaris Monocline, through the Carrum Swamp area, to the Cranbourne Sand ridges of the northern part of the Mornington Horst. It is suggested therefore that a genetic relationship may exist between the sandy ridges of the Brighton Coastal Plain, the Carrum Swamp area and the Mornington Horst, these respectively being little modified, partially blanketed by alluvial and swamp deposits and extensively wind modified, probably during the Pleistocene.

Further east, in the area north of Inverloch, towards the South Gippsland Uplands there is an extensive area of Tertiary ferruginous sands and clays which show a very distinct northwest-trending, subdued ridge and intervening swamp terrain. This is a pattern more akin to a progressively retreating coast than that which would be expected in outwash fans from the adjacent uplands, or to have developed on emerged sub-aqueous beds, nor can the pattern be satisfactorily explained by tilting.

On the coastal plateau east of the Gippsland Lakes (the piedmont fringe of Talent 1969) there are marked alignments in the tributary drainage parallel to the present coast (Fig. 1). These trends intersect the dominant structural grain and appear on Tertiary clastic sediments of varying texture, some of which have been extensively ferruginised. The trends also appear on Palaeozoic sedimentary rocks and granites which carry scattered residuals of Tertiary sediments and may represent a superimposed drainage pattern.

A coastal origin, or at least influence in the formation of these ridges and trends particularly those of southern Victoria, has not been established with certainty, but their apparent independence of direct structural control and their alignment parallel to the present coast, and normal to the dominant swell approach implies such a relationship. The varied composition of the sediments does not suggest a dune origin for the ridges, although aeolian reworking of older sediments may account for the strong alignments



in the Cranbourne Sand deposits between Port Phillip and Western Port, and the dunes overlying the Moorabool Viaduct Formation on the Bellarine Peninsula. The wide separation of the Cranbourne Sand ridges seems to preclude normal transverse dune formation, and longitudinal dune formation is most unlikely, assuming that the dominant wind direction has not changed markedly through later Cainozoic time.

Undoubtedly, the later Tertiary deposits in southern Victoria call for detailed study, especially in geomorphic context, in view of their obvious physiographic importance in relatively elevated coastal areas.

In lower-lying regions, such as the Gippsland Lakes—Latrobe Valley depression, the Tertiary marine sediments are usually blanketed by Quaternary deposits. In this area, although the limits of Tertiary marine sedimentation have been defined from subsurface data and sporadic outcrop, little is known concerning the precise nature of the coastal environments. On Mississippi Creek, to the north of Lakes Entrance, the edge of the Early to Middle Miocene Gippsland Limestone appears as a boulder and gravel bed, with abundant shells, transgressing the granite bedrock, undoubtedly a beach or near shore deposit. Highly ferruginised shelly beds also occur near the Brodribb River, east of Orbost, closely defining the Miocene coastline in this area. Further west, in the axis of the Latrobe Depression, deposition of the marine Gippsland Limestone and the terrestrial Morwell and Yallourn Formations continued synchronously (Abele *et al.* 1976) but the detailed inter-relationships between the two is uncertain. The Late Miocene (Tambo River) and Early Pliocene (Jemmys Point) formations represent a regressive phase following the maximum Middle Miocene (Gippsland Limestone) transgression. In the Lake Wellington area the beds between the wholly marine Jemmys Point Formation and the overlying non-marine Boisdale Formation appear to be transitional near-shore deposits. Their facies similarity to Recent deposits in Lake Reeve was noted by Jenkin (1968) who suggested that tidal flats, lagoons and barriers were present at that time. The view that these beds are late transgressive phases of the otherwise regressive Jemmys Point Formation (Hocking 1972, 1976) is consistent with this interpretation. Beds overlying the Jemmys Point Formation near Lakes Entrance have been described as lagoonal (Wilkins 1963), implying the presence of a seaward barrier, and recently a sandy sheet lying between the undoubted marine section of the Jemmys Point For-

mation and the overlying, supposedly estuarine beds has been interpreted as a barrier remnant (Carter 1979). Succeeding the estuarine beds is a second sand body, also believed to represent a Pliocene barrier, which interdigitates on the landward side with supposed lacustrine sediments.

Although the sands undoubtedly indicate near shore conditions, there is as yet insufficient information to define precisely the forms represented. From the evidence, the sands could be sand tongues or shoals (in the terminology of Reineck & Singh 1975) rather than barriers in the true sense, or both forms may be present contemporaneously or in succession. Nevertheless, there have undoubtedly been changes in relative sea level in the Gippsland Lakes area during the Pliocene. These have been attributed to eustatic sea level fluctuation (Carter 1979).

In general, regressive deposition was dominant in southern Victoria during Late Miocene and Pliocene time, although several readvances have been recorded (Hocking 1976, Abele *et al.* 1976, Carter 1979). In the Murray Basin however, a distinct transgression occurred during the Late Miocene and Early Pliocene, to be followed by continuous regression through the remainder of the Pliocene. These advances do not appear to be contemporaneous and probably occurred over different time spans in different areas; in the Port Phillip basin from Late Miocene into the Early Pliocene, in South Gippsland during the Early Pliocene and in East Gippsland during Mid and Late Pliocene.

There is little doubt that the relative changes in Late Tertiary sea level in Victoria have been influenced by differential earth movements in addition to eustatic effects. World-wide comparisons also suggest the dominance of regression through most of the Pliocene (Fleming & Roberts 1973), but the evidence for widespread synchronous advances during that period is ambiguous.

#### THE PLIO-PLEISTOCENE BOUNDARY

Late Pliocene to Pleistocene marine deposition is rare in on-shore southeastern Australia, except perhaps in the western part of the Otway Basin where the Coomandook and Whalers Bluff Formations were deposited in shallow embayments. However the deposition was diachronous, becoming progressively younger and thicker towards the west (Kenley 1971, Abele *et al.* 1976), while being interrupted on the eastern side by the Greenwald-Cobboboonee Basalt (2.2–3.1 m.y.). The Plio-Pleistocene boundary is taken at 2 million years B.P. (Lambert 1971). Kenley (1976) used 1.8 m.y.,



following the 1948 INQUA definition, and judged by the K-Ar datings on Victorian basalts (Abele *et al.* 1976), this does not affect the generalisations outlined above.

Elsewhere in Victoria, except perhaps in the Sorrento Graben and the Otway and Gippsland offshore areas, there seems to have been a cessation of marine deposition following the Early Pliocene and extending into the Early Pleistocene. Initially this was marked by widespread deep weathering (lateritisation). If this palaeosol is not diachronous, and was formed during a short period, it would be a reliable and, because of its widespread occurrence, useful approximate indicator of the Pliocene-Pleistocene boundary. The youngest deposits affected appear to be Late Pliocene (Moorna Formation, Gill 1966). However it is possible that this formation is equivalent to the Early Pleistocene Blanchetown Clay of the Murray Basin (Lawrence 1976). Elsewhere, the lateritisation is confined to Late Pliocene or older formations. On the Port Campbell coastal plain a similar soil formation has been called the Timboon Pedoderm and equated with similar occurrences in northwestern Victoria (Gill 1973b).

The intensity of the weathering seems to have diminished eastwards from Western Port, although in far East Gippsland deep lateritic profiles have been recorded (Talent 1969). In the Gippsland Lakes area, the most intense ferruginisation affects the top of the Boisdale and Coongulmerang Formations, and should not be confused with local massive ironstones and weaker general oxidation in the Haunted Hill Gravel (Jenkin 1968).

There is little doubt that deposits resting on this widespread pedoderm, or on landforms cut into it, are Late Pliocene or Quaternary in age. It is therefore a useful datum in relation to the fragmentary younger marine deposits along the present coast, for example those lying at a high level at the seaward edge of the Port Campbell coastal plain, and which do not contain diagnostic fossils.

#### PLEISTOCENE CONDITIONS

The early Pleistocene sea, at its maximum extent in south-western Victoria, reached the foot of the Kanawinka scarp, and it was during this period that the greater part of the Whalers Bluff Formation was deposited (Kenley 1976). The subsequent retreat resulted in the stranding of successive subparallel calcareous aeolianite dunes and coastal barriers, collectively known as the

Bridgewater Formation (Boutakoff & Sprigg 1953, Boutakoff 1963, Kenley 1976). Similar aeolianite ridges occur in the embayment east of Portland and at Warrnambool, where Gill (1967, 1976), and Gill & Gill (1973), have described a succession of aeolianites thought to represent early, mid and late Pleistocene interglacials. The oldest, or "early" aeolianite is the highest of the series, and has been tentatively dated at 700,000 years B.P. The position of the innermost Pleistocene shoreline in south-western Victoria can therefore be plotted with some assurance.

Further east, in the Peterborough-Port Campbell area, high-level terraces along the sides of the Curdie and Port Campbell estuaries may be related to Pleistocene high sea levels, although the only definite marine or coastal deposits occur as remnants close to the present coast. In the Port Phillip Sunkland coastal features may, on the basis of field relationships and with some certainty, be referred to the earlier Pleistocene. Shelly sands and gravels at Portarlington were considered by Jutson and Coulson (1937, 1940) to be early Pleistocene, and the easternmost aeolianites of the Bellarine Peninsula (Jenkin 1968, 1974) may be of a similar age. The only specific date relates to the Fishermens Bend Silt in the Yarra Delta which, deposited in a shallow marine embayment, is about 800,000 years old (Neilson 1976).

In Western Port it is unlikely that marine sediments of Pleistocene age are present (Marsden & Mallett 1975), and fluvial activity was dominant. In south-east Gippsland extending from Corner Inlet to Lakes Entrance, there is considerable doubt concerning the identification and age of the supposedly marine Pleistocene forms and deposits, the only undoubted occurrences terminating at former cliffs behind the Inner Barrier, or being represented by shell beds in estuarine and deltaic areas.

#### SEA LEVEL CHANGES

Changes in the relative levels of land and sea in Victoria have been established by many workers, and interpretations have been based on glacioeustasy, local tectonics, or combinations of both.

The occurrence of Plio-Pleistocene sediments of undoubted marine origin and the overlying succession of dune ranges at successively lower levels in south-western Victoria, interpreted as marking still stands during the retreat of the Pleistocene sea, indicate an overall fall in relative sea level of about 65 metres over that period (Boutakoff 1963,



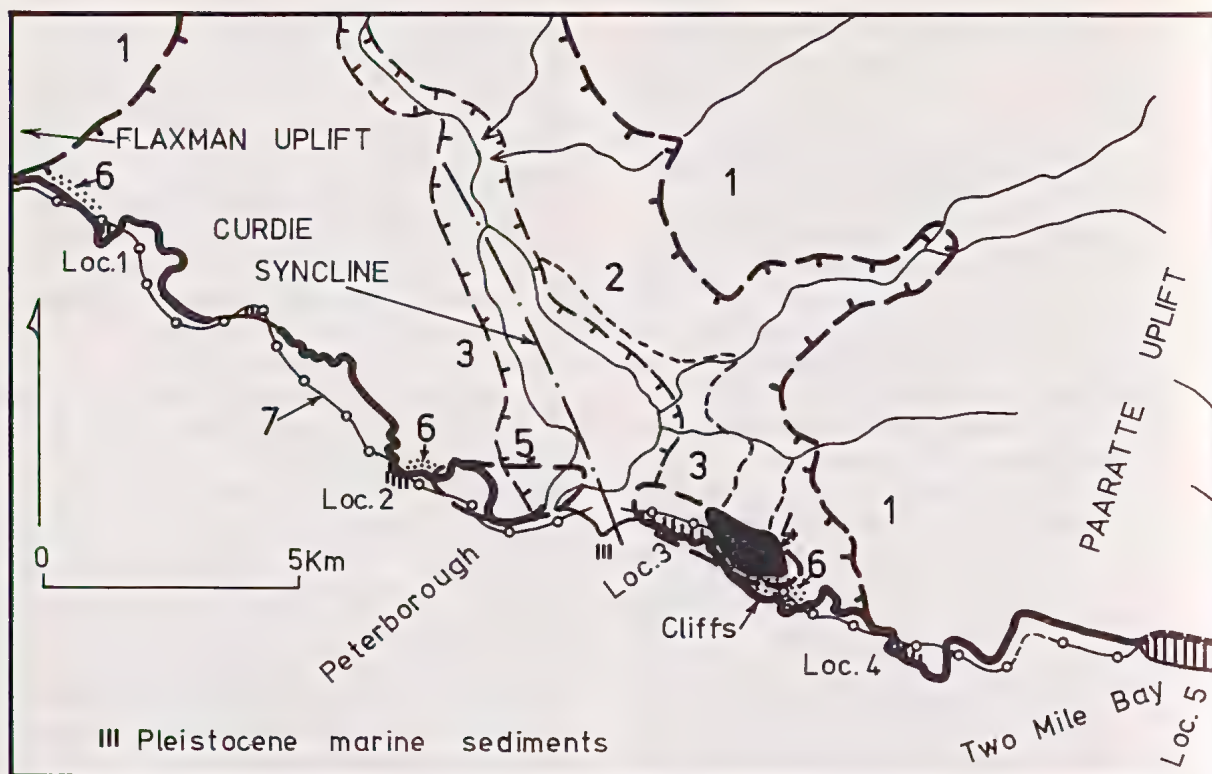


FIG. 2—The coast near Peterborough, western Victoria:

1—High; 2, Intermediate and 3, Low terraces; 4, Aeolianite; 5, Possible original extent of aeolianite; 6, Red-brown cliff-top dunes; 7, Limit of Pleistocene marine sediments.

Kenley 1971, 1976). Breaching and truncation of previously formed dunes during glacioeustatic rises of sea level have also been suggested (Kenley 1976). In the south-east of South Australia a similar series of ridges has been described (Hossfeld 1950, Sprigg 1952, Boutakoff & Sprigg 1953). Recent work between Narracoorte and Robe suggests that at least twenty major high sea level stands have occurred over the last 690,000 years (Cook *et al.* 1977). Periodic readvance was also found in South Australia.

Earth movements also occurred in the Gambier Embayment in southwestern Victoria during the Pleistocene and include both broad epeirogenic movement and local deformation associated with vulcanicity (Boutakoff 1963, Kenley 1976). In South Australia, Pleistocene uplift has been attributed, in part, to movements associated with Mt. Gambier and Mt. Burr volcanic activity (Cook *et al.* 1977).

In the Warrnambool-Port Fairy district a sequence of marine and aeolian sediments, possibly deposited over the last 700 000 years, and incorporating three glacial and three interglacial

periods has been proposed (Gill 1967, 1976, Gill & Gill 1973). Tectonic stability during the Quaternary was assumed. However the sequence encompasses three volcanic events, namely extrusion of the Yangery Basalt (1 950 000 yr), the Woodbine Basalt (300 000 yr) and the Tower Hill Tuff (c. 4000 to 7000 yr). The area also straddles the Warrnambool High, over which there is marked thinning and facies variation in certain of the Late Cretaceous and some Tertiary formations (Spencer-Jones *et al.* 1971, Taylor 1971, Abele *et al.* 1976).

There is no doubt that the Warrnambool High and its flanking troughs were tectonically initiated and it seems likely that earth movement has continued, although spasmodically to the present. Further support is provided by Leslie (1966), who pointed out that the area coincident with the subsurface ridge is geomorphically distinct, being better drained than the plains to the east and west.

At Peterborough, 30 km to the east, the Mid Miocene Port Campbell Limestone has been warped into a broad syncline, the axis of which coincides approximately with Curdie's Inlet. This

was first indicated by Wilkinson (1865) and recently confirmed from dips observed in the shore platforms. The area however, also provides evidence of earth movement of more recent date. Quaternary coastal deposits and landforms have been known here for some time. Gill (1947) noted a platform carrying marine deposits at 3.7–4 m above present mid-tide level at Flaxman's Hill, west of Peterborough, and deposits resting on a 3 m platform at Two Mile Bay near Port Campbell have been described by Baker and Gill (1957) and Ollier and Joyce (1973). The most continuous Quaternary marine section however forms the upper part of the cliffs immediately south-east of Curdie's Inlet and shows thin beds of shallow water calcarenite resting on planar surfaces on Tertiary mottled clays which contain a variably eroded upper buckshot layer (Fig. 3). Two such surfaces are present, an upper one dipping westwards at a very low angle ( $0.3^\circ$ ), and a lower one dipping at  $0.5^\circ$ W which terminates the higher surface at about 22 m above the contemporary shore platform (m.s.l.). The calcarenite forms a persistent layer on the steeper surface down to an elevation of about 8 m. The present cliff then drops to an emerged shore platform lying at 4.5 m above m.s.l. The calcarenite on the upper surface wedges out towards the east and is preserved where it is covered by aeolianite. The red-brown, slightly calcareous dune sands, which further east rest directly on the Tertiary clays, also partly mask the aeolianite and are regarded as being younger. West of the aeolianite ridge, highly calcareous dunes cover the calcarenite, and are succeeded at the western end of the section by younger dunes.

West of Peterborough (Loc. 2, Fig. 2) there is a well-developed platform at +7 m carrying up to 3.5 m of well-bedded shelly sands and associated shell beds. There is also a lower platform at about +5 m. On the adjacent cliff top, and also at Peterborough, calcareous red-brown dune sands rest on Tertiary clays, but at a lower level than those at Loc. 3 (Fig. 2), (14–15 m) and on a surface dipping east towards the Curdie Syncline. Further to the west again (Loc. 1, Fig. 2), calcareous marine burrowed silty sands occur at about +34 m, and red-brown dunes similar to those at Localities 2 and 3 are also present.

At Point Hesse (Loc. 4, Fig 2) marine shallow-water calcarenites also occur at about the same height (+31 to +35 m).

Two points are of particular interest. Quaternary deposits and forms which can be attributed directly to marine activity are limited to a very narrow strip adjacent to the present coast.

Secondly, the red-brown dunes occur at different levels on surfaces which slope towards the axis of the Curdie Syncline. If sea levels rose to the heights indicated by the marine deposits, Curdie's Inlet would have expanded to become a large embayment with a string of shoals and possibly sand bars separating it from the open ocean. The water in the centre would have been about 35 m deep at the time of highest sea level, shallowing towards the marginal terraces. Deposits in the Curdie Depression however consist predominantly of clays and sandy clays typical of the present river floodplain and swampy inlet margins. No marine deposits have been found inland from the coastal strip.

It is therefore suggested that the marine deposits were formed close to present sea level and that the whole area has been subject to uplift, that to the east (Paaratte) and to the west (Flaxman's Hill) being greater than in the axis of the Curdie Syncline. At each stillstand a broad flood plain would have formed, successive uplift and subsequent erosion resulting in flights of lateral terraces. This proposal does not exclude the possibility of eustatic sea level changes, but the alternative that the marine deposits are the result of sea levels much higher than at present and that the Curdie Depression has been formed by subsequent downwarping appears unlikely. Nor does extensive erosion following each drop in sea level explain the existence of this broad valley as the sediments carrying the lateritic Timboon Pedoderm have not been deeply enough dissected and the younger deposits on the terraces are quite thin.

The age of the Quaternary marine deposits in this area is speculative. The Two Mile Bay deposits are beyond the range of  $C^{14}$  dating (Baker & Gill 1957) but, like the deposits at Loc. 2, they contain *Ninella torquata* which has been dated at several points further west. At those points it appears to indicate an age in the range 100 000 to 125 000 yr. B.P. (Gill 1976).

## SEA LEVEL AND PLATE TECTONICS

Plate tectonics may influence sea level in two ways, firstly by changing the form of the Earth's crust, thereby producing tectono-eustatic changes, and secondly by changing the elevation of the continental margin relative to the sea. A maximum eustatic rise of 300 m (260 m related to sea floor spreading and 60 m to glacial melting) in the Mid Miocene has been suggested by Fleming and Roberts (1973). They pointed out that, if this were so, all Mid Miocene marine features now above 300 m would have attained their position by uplift. The implication as far as Victoria is concerned is



that the entire Mid Miocene marine transgression, and the subsequent regression, could be accounted for eustatically without the intervention of local tectonics. The maximum fall in sea level suggested was 800 to 1000 m in the Mid Miocene indicating that the continental shelves and the upper parts of the slopes would have been subject to subaerial influences at that time. In Gippsland the Early Miocene to Mid Pliocene sequence appears to be essentially conformable, although James and Evans (1971) and Hocking, *et al.* (1976) describe an Early Miocene slump zone, the formation of which was attributed to the reactivation of the Foster Fault system (Fig. 1). Later in the Miocene several "submarine channels" were produced, attributed to structural movements and associated sea level changes, although the precise nature of these was not specified.

In general, where the edges of continents are near plate margins, large scale earth movements may be expected (Curry 1965). These are likely to decrease away from the plate margins but complete stability must be questioned anywhere (Komar 1976). The effects on continental margins are expected to depend on the nature of the plate boundaries. Inman and Nordstrom (1971) for example, suggest that there is a close correspondence between the main morphological and plate tectonic features of coasts. Thus, the east coast of Australia, including eastern Tasmania and the Victorian coast east from Port Phillip is mapped as a collision coast, which is supposed to be characterised by a continental shelf less than 50 km wide, by coastal mountains more than 300 m high, and by a rocky, cliffed shore zone with occasional pocket beaches. When collision ceases, these coasts become maturely eroded and hilly, rather than mountainous. The coast west of Port Phillip is regarded as a trailing edge coast, that is it lies on the non-collision side of the continent and is supposed to be actively modified by the depositional products and erosional effects from an extensive area of high interior mountains, in this case the Murray drainage basin. This is the "wide-shelf plains coast" typified by low-lying coastal plains, a wide shore zone, and barrier beaches. Some features of these coasts would fit some of Inman and Nordstrom's criteria, but the correspondence is not close, as will be seen from the tectonic subdivision of the coast discussed in the next section. The Victorian coast, at least as far west as the Dartmoor Ridge, certainly appears to be anomalous in terms of their classification.

Ollier (1978) has pointed out that earth movement in the highlands of south-eastern Australia

has been dominantly vertical throughout Cainozoic time. The block structures of southern Victoria fit this concept although a complication is the marked kink in structural trends (Harrington *et al.* 1974) which suggests some east-west slip between Victoria and Tasmania. Cainozoic trends in Bass Strait, however, indicate that general foundering coupled with differential internal block movements, were dominant during that time.

While agreeing with Ollier that no pattern of drift, or current plate tectonic theory, can adequately explain the age, orientation or structure of the Eastern Highlands, there is the possibility that northerly drift of the Australian plate has resulted in rifting between Victoria and Tasmania. Assuming that the Australian plate is drifting northwards, southern Australia becomes the trailing edge, and tension normal to the direction of plate movement might be expected, resulting in the detachment of crustal fragments. Thus, Tasmania could be in the process of splitting off from the mainland. This would have far-reaching effects on relative sea levels in and adjacent to the rift zone.

## CONTRASTS IN COASTAL SEGMENTS

Victorian coastal configuration is dominated by two factors, namely the direction of swell approach (Bird 1961) and the tectonic style.

The effect of the dominant swell can be traced back to the Mid Tertiary at least, producing two segments of contrasting coastal orientation separated by the Bassian Rise (Jennings 1959), represented on land by Wilson's Promontory.

To the east of the Bassian Rise, south-easterly swell is dominant, while to the west, a south-westerly swell dominates. At present, there is some interaction between the two in eastern Bass Strait but during very low sea levels in the Late Quaternary and possibly the Miocene, the Bassian Rise would have been a land area dividing Bass Strait from the Tasman Sea and preventing swell interference between the two. The effect is shown by the orientation of both Quaternary and Late Tertiary barriers and other wave generated shore line features (Figs 1, 4), which face the direction of the refracted wave approach.

The tectonic division, however, is the Dartmoor Ridge far to the west (Fig. 1). In the Gambier Embayment, west of the Dartmoor Ridge, the Pleistocene sea extended inland to the Kanawinka escarpment (Kenley 1976), but to the east it did not reach far beyond the present coast. West of the Dartmoor Ridge the dominant fault trends are NW to NNW (Spencer-Jones *et al.* 1971) while to

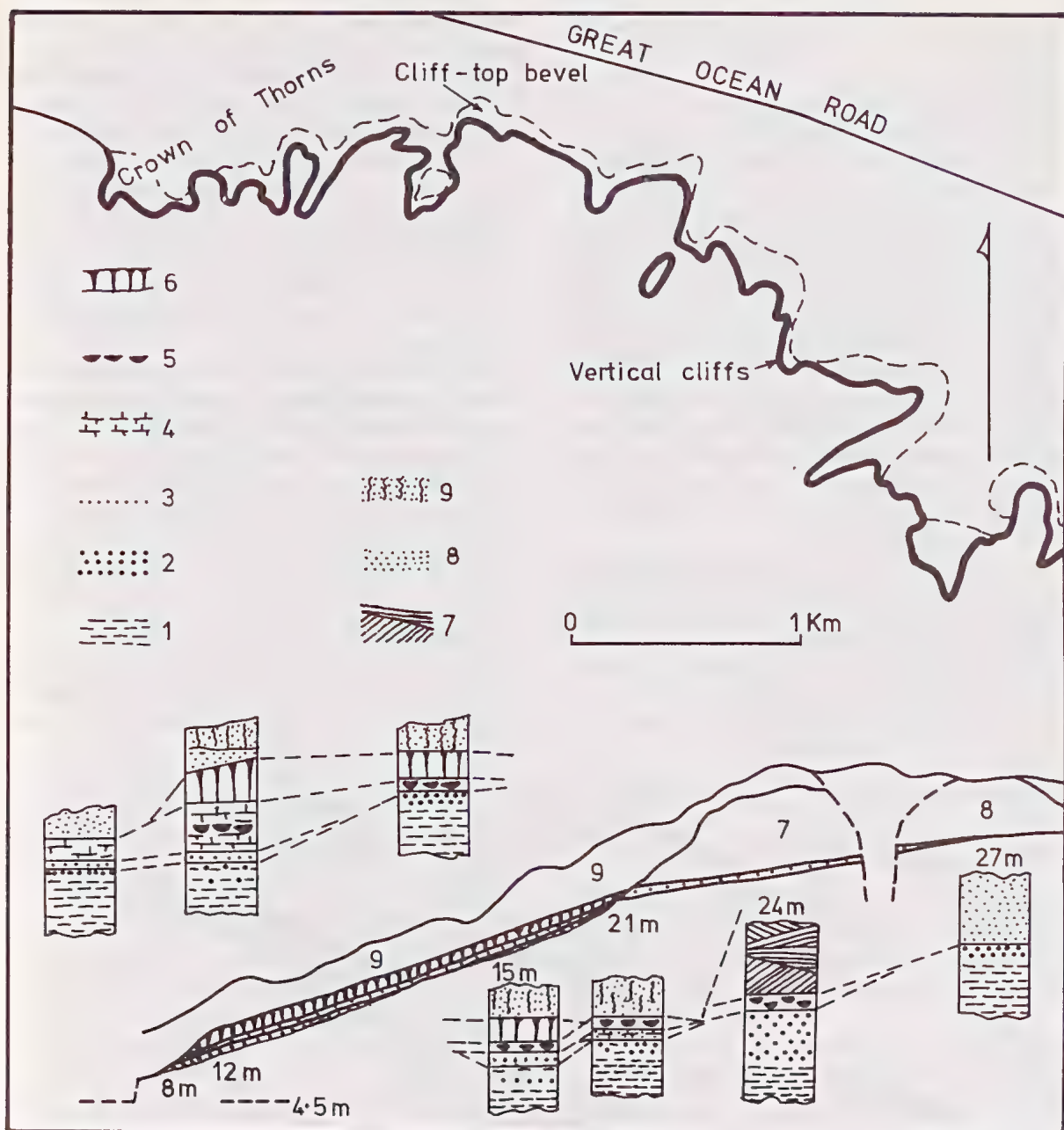


FIG. 3—Crown of Thorns area, east of Peterborough:

1—Mottled clay (Pliocene); 2, Buckshot, *in situ* and reworked; 3, Calcareous sand; 4, Bioturbated calcarenite; 5, Scoured calcarenite; 6, Calcareenite with vertical burrows; 7, Aeolianite; 8, Red-brown dune sands; 9, Calcareous dune sand with abundant rhizomorphic concretions.

the east they are N to NE, with east-west trends becoming conspicuous E of Wilson's Promontory (Fig. 1).

In the Gambier Embayment the main structural trends are oriented in a similar direction to the refracted wave fronts, while on the remainder of

the coast the two lie at an appreciable angle. A broad embayment with an extensive series of parallel barriers is characteristic of the first condition. In the second there is a succession of alternating headlands, truncated plateaux and relatively small embayments along the coast, pro-



viding a framework for highly varied local coastal development.

#### SEA LEVEL FLUCTUATION AND INSTABILITY OF THE LAND

Tindale (1933) considered the possibility of eustatic variations in sea level, and their correlation with European glacial phases in connection with raised strandlines in South Australia. Similar suggestions were made in Tasmania by Lewis (1935) and Edwards (1941). In Victoria, Hills (1940) systematically examined the problem of eustatism and tectonics and pointed out that shell beds then designated as Recent and since shown to be so by  $C^{14}$  dating, lie at different elevations above sea level. Hills concluded that at least part of the emergence was due to tectonic uplift. At the same time he suggested that, as evidence of Recent emergence was so common, a eustatic fall in sea level was a likely contributor.

The succession of so-called dune ranges and raised beaches in South Australia has attracted particular attention (Crocker & Cotton 1946, Hossfeld 1950, Sprigg 1948, 1952). Sprigg (1952) attempted to correlate the high sea levels (raised beaches) with the Mediterranean sequence as defined by Zeuner (1945) and with the

Milankovitch (1938) radiation peaks. He showed that the dune ranges had been tilted towards the west, the older dunes being tilted at a greater angle than the younger. Boutakoff (1952) noted the continuation of Pleistocene strandlines into Victoria. They are also tilted towards the west and fan out in a westerly to north-westerly direction from the Portland area which was regarded as being tectonically stable (Boutakoff 1963). Direct correlation with the European (mainly Alpine) chronology was attempted, equating features around Portland with the Pleistocene glacials and interglacials.

Until recently this supposed relationship has strongly influenced most workers in this field in Victoria (Gill 1967, 1971, 1976, Ward & Jessup 1965, Jenkin 1968, Ward 1966). Ward *et al.* (1971) proposed a correlation of features, interpreted in Gippsland as former shorelines, with marine terraces in South Carolina and Ward (1977) also linked Holocene shorelines in Gippsland, after allowing for uplift, with those in the Firth of Thames, New Zealand.

There is general acceptance that climatic fluctuations causing glacial advance and retreat result in corresponding changes in sea level, and a more credible, positively datable sequence of these

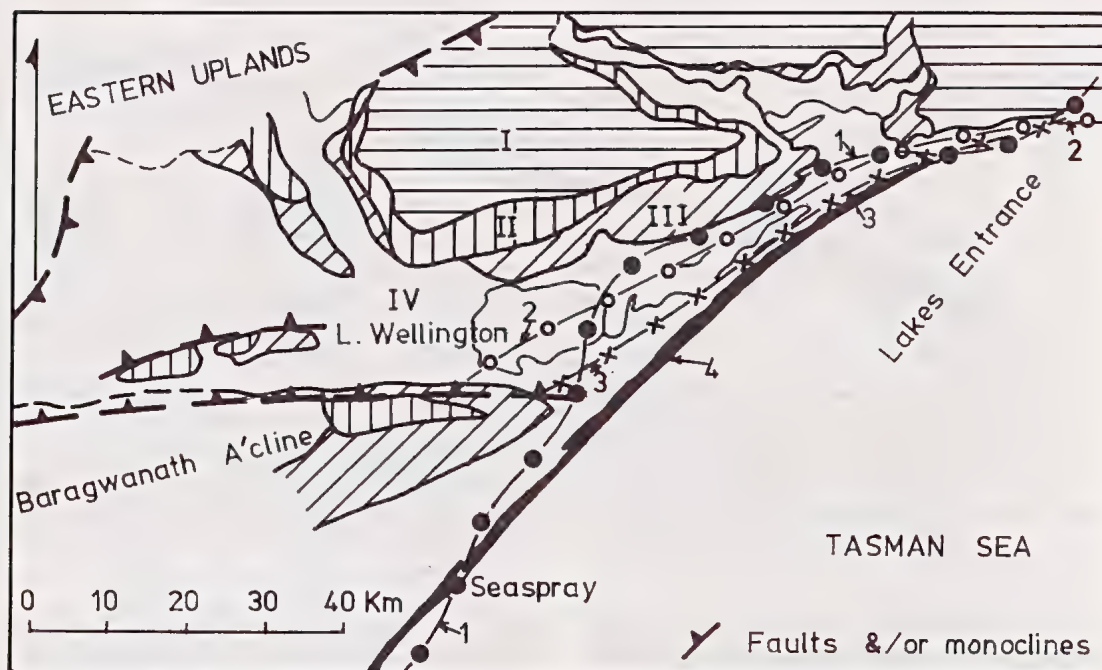


FIG. 4—The Gippsland Lakes area:

I, II, III—High-level benches, ?E. to M. Pleistocene; IV, Late Pleistocene delta complex; 1, Possible Pliocene barrier; 2, 3, Late Pleistocene barriers; 4, Outer (Holocene) barrier.

events on a world-wide scale seems now to be emerging. This is essential if the relative significance of eustatic and tectonic factors is to be reliably evaluated.

Oxygen-isotope study of deep sea cores, where sedimentation is likely to have been continuous and to reflect oceanic temperature changes, has produced a succession of stages which, coupled with magnetic measurements and  $C^{14}$  dating, can be used to date climatic changes over the last 850 000 years (Shackleton & Opdyke 1973). The 16 metre equatorial Pacific core showed 23 isotope stages, the nineteenth stage coinciding with the boundary between the Brunhes and Matuyama magnetic epochs, which has been dated at 700 000 years. Cores from the Southern Ocean show some significant differences from the equatorial sequence where distinct fluctuations indicated by the Antarctic core are obscured in the tropical core by sediment disturbance due to burrowing organisms, particularly in Isotope Stage 5 (Hays *et al.* 1976, Shackleton 1978).

Other approaches include plotting carbonate abundance (Frakes 1978) and the abundance of temperature-dependent radiolaria and foraminifera (Keaney & Kennett 1972). Frakes showed that in the Brunhes magnetic epoch, that is, over the last 700 000 years, cold intervals are more regular, more closely spaced and better defined than in the Matuyama epoch, that it is generally cooler, and that there seems to be a trend towards generally warmer conditions over the last 450 000 years.

Dating of emerged coral terraces has also thrown light on changes in sea level. In New Guinea, Chappell (1974) examined a series of clearly-defined terraces progressively uplifted tectonically to a maximum height of more than 600 metres. Radiometric dating of shallow water coral faunas showed nine periods of high sea level going back 20 000 years. It was also shown that, if a uniform rate of uplift was assumed, the high sea level stands were mostly below present sea-level. More recently Chappell and Veeh (1978) have confirmed these results, with extrapolation back to 700 000 years B.P., in North Timor and at Atauro Island. They point out the closeness of the correlation between the main periods of glacioeustatic rise and those indicated by the oxygen isotope profiles from Pacific cores.

There appears to be sufficient agreement between the curves produced using the various techniques now available, despite some discrepancies, to lend encouragement to the view that a reliable chronology of events during the last few million years may soon be developed.

## NEOTECTONICS

Relief-forming movements of the earth's crust are described as neotectonic (Bondarchuck *et al.* 1959). There is no doubt that neotectonic movements have occurred in Victoria as was shown by Boutakoff (1963) and Kenley (1976) in south-western Victoria, Hills (1940) in the Port Phillip Sunkland, and Boutakoff (1955) and Jenkin (1968) in south-east Gippsland. Undoubted neotectonic effects have been recognised inland (Bowler 1978, Bowler & Harford 1966) and it is thought that the phenomenon has been significantly under-estimated in south-eastern Australia. Recent work in the Peterborough-Port Campbell area (above) suggests appreciable Quaternary movement and Bird (1965) has suggested that uplift at the intersection of the Rosedale Fault and the coast has initiated barrier formation in the Gippsland Lakes area.

## REGIONAL AND LOCAL EARTH MOVEMENT

On several parts of the Victorian coast there is definite evidence of emerged Holocene shell beds and the apparent diversity of tectonic environments for these occurrences has been relied upon previously in attempts to establish the existence of Holocene sea levels higher than the present level (Gill 1971, Jenkin 1968).

The history of south-eastern Australia through the Cainozoic seems to have been one of general uplift, accompanied by differential block faulting, particularly in the Eastern Highlands province (Ollier 1978), but varying in intensity, as proposed by Wellman (1979). It is suggested here that apparent Holocene still stands above the existing sea level can be adequately explained by such earth movements.

The precise tectonic effect, however, would vary with the tectonic pattern and the level of activity. Emerged Holocene shell beds in Victoria are in a region which appears to be tectonically active compared with the sections of eastern Australian coast studied by Hails (1965), Hails and Hoyt (1968), and Langford-Smith and Thom (1969). A possible exception is shown by work in the Shoalhaven valley of the South Coast (Walker 1958, noted by Langford-Smith and Thom (1969). This occurrence, like those in Victoria, is in what appears to be a more tectonically active section than are the Holocene deposits further north.

Successions of older raised shorelines have been recognised in New South Wales (Hails & Hoyt 1968) and Victoria (Gill 1967b, Jenkin 1968). As pointed out previously, those in the Gambier Em-



bayment (Kenley 1971) are unique as far as Victoria is concerned and will be considered separately.

The recorded levels (m) are:

NSW	Gippsland	Warrnambool- Port Campbell
1.6-3	3.3	3
3.7-4.5		3.7-4 4.5-5
6-9	8	7.5 8.5
12-15	15	10.5 21
24-30	*	23.5 28 31

\* Higher levels have been proposed for the area north of the Gippsland Lakes (Jenkin 1968, Ward 1977). However, an alternative origin for these features is suggested below.

On present information, no direct correlation of the observed levels is feasible, principally because little accurate dating has been done and insufficient precise longitudinal topographic data are available regionally. Nevertheless, there is sufficient information from certain critical areas on which to base some generalisations. Dating of corals from the Inner Barrier at Evans Head on the north coast of New South Wales for example has given ages between the limits of  $112\,000 \pm 9\,000$  and  $127\,000 \pm 18\,000$  years, the deposits being related to a sea level of 4 to 6 metres above the present mean. Dates obtained from Newcastle Bight ( $142\,000$  and  $143\,000 \pm 12\,000$  yr BP) could be related to a previous transgression. No definite older marine deposits at higher levels were found and it was inferred that the sea returned approximately to the Inner Barrier level at each period of high sea level which occurred during the past 700 000 years (Marshall & Thom 1976). Stranded marine deposits, undoubtedly older than dated Holocene shell beds, have been recorded from various parts of the Victorian coast. Shells from the Port Fairy Calcarene, which is related to a mean sea level of about 7 m, have been dated at 125 000 BP (Gill 1967, 1976). An earlier high sea level is indicated by the Sunnyside Sand, shells from which gave a date of about 400 000 yr BP (Gill & Amin 1975).

The well-preserved, but mostly disconnected occurrences of undoubted pre-Holocene shore zone sediments in the adjoining Peterborough-Port Campbell area have not yet been dated. However, despite undoubted tectonic effects, they also in-

dicate sea level fluctuations. The 7 m platform at Loc. 2 (Fig. 2), which carries at least 3.5 m of Pleistocene sub-aqueous sediments, is obviously an inherited feature. The 3 m platform at Two Mile Bay (Loc. 5, Fig. 2) could also belong to this category.

Pre-Holocene shoreline deposits above present sea level are rare in the Port Phillip area. Exceptions are the aeolianites of the Nepean Peninsula and Queenscliff, the shelly sediments at Portarlinton (Jutson & Coulson 1937) and the Picnic Point deposits at Hampton (Gill 1950). The only shoreline deposits which are now at a high level are those at the eastern end of the Nepean Peninsula, where they are thought to have been uplifted by movement on Selwyn's Fault (Jenkin 1968). As tectonic stability cannot be assumed for Portarlinton and Hampton, there is no undoubted evidence in Port Phillip for Pleistocene sea levels above the present.

In Western Port there is no evidence of Quaternary marine or shoreline sediments older than Holocene (Marsden & Mallett 1975). It is likely that, during the Late Pliocene, and certainly during the Pleistocene, Western Port was gradually subsiding, but that no Pleistocene sea level was high enough to inundate any part of the area. Western Port is thought to have been cut off from the ocean by barriers behind which were swampy lowlands and shallow lakes, the associated deposits being represented by sands, sandy clays and clays at Woolamai Beach, Cat Bay, Flinders and possibly north-west French Island and Warneet (Jenkin 1962). In both Port Phillip and southern Mornington Peninsula also, deposits of fresh or brackish-water limestones occur in valleys whose drainage was probably impeded by barrier or estuarine marsh development.

In south-eastern Gippsland, retreat from the Mid Miocene maximum marine advance is indicated by the regressive late Miocene Tambo River Formation (Carter 1964). Regression continued in the Pliocene, except in the Alberton-Welshpool area where a local readvance, probably related to downwarping, has been recorded. The occurrence of barriers and lagoons with successive marine, brackish, then freshwater deposition as the sea retreated through the Pliocene in the Gippsland Lakes area, foreshadowed by Jenkin (1968), has recently been confirmed and elaborated by Carter (1979). These deposits were finally over-run by the dominantly terrestrial Haunted Hill Gravels which are variably exposed on the coastal plateau, as it was termed by Bird (1961), north of the Gippsland Lakes.



The plateau is benched and carries sand ridges of varying form and height. Two of these benches were interpreted by Jenkin (1968) as representing Mid Pleistocene sea levels. Ward (1977) subsequently accepted a marine origin for these features and extended the sequence, thus:

Jenkin (1968)		Ward (1977)
	8 m	Late Pleistocene
	11 m	(younger)
27-30 m	20 m	Late Pleistocene
	21 m	(older)
33-36 m	38 m	Mid Pleistocene
> 36 m	49 m	
	79 m	Early Pleistocene
	110 m	
	128 m	

The discrepancies in levels, up to about 6.5 m, appear to be mainly due to the different criteria used. Jenkin used the general level of the bench at the inner break of slope whereas Ward used specific levels requiring interpretation of various sedimentological and morphological features, viz. highest beach level, highest well-sorted sediments, level of tidal marsh, lowest undissected land inland of shore. A major difficulty with the marine bench hypothesis is that no undoubted marine deposits have been found on them. Because the scarps face SSE towards the sea and join undoubted fluvial terrace facets at a very sharp angle, they were presumed to be marine. It was also suggested that many of the sand ridges associated with the benches could best be interpreted as coastal barriers and submarine bars (Jenkin 1968). Ward (1977) does not accept that any of these ridges are submarine in origin, but rather that they represent shoreline deposits stranded during coastal retreat.

An alternative to a direct marine origin for the benches and their surface features involves successive fluvial, deltaic and aeolian deposition with contemporaneous development of a coastal barrier sequence, coupled with earth movements of two kinds. It has been suggested that, in the Gippsland Lakes area, Late Pleistocene flood plain, delta flood plain and barrier features form a more or less contemporaneous depositional complex (Jenkin 1968). The later discovery of shell beds, dated at 101 000 yr BP (Schornick 1973), lateral to a supposed deltaic stream levee, helps to confirm this environmental reconstruction. Streams entering the Latrobe Depression at this time were diverted towards the east into lagoons

or lakes behind the Inner, or Prior, Barrier. A broadly similar situation applies at the present time, and it is also suggested that these conditions could have been operative intermittently through the earlier parts of the Pleistocene, and back into the Tertiary.

Work of Jenkin (1968), on the earlier Pleistocene, and of Ward (1977) may be reinterpreted and, instead of viewing Tertiary conditions as being essentially different from those of the Pleistocene, and Holocene, definite although complex repetitions can be identified. Thus, the benches on the coastal plateau possibly represent a succession of delta flood plains formed in tectonically stable periods between intermittent episodes of differential earth movement. Coastal plateau rise coupled with depression on the Latrobe axis seems to be a necessary accompaniment, otherwise Pleistocene marine or estuarine deposits would occur far inland to at least 40 km beyond their known limits.

The higher level cliffs, previously regarded as marine, are therefore interpreted as fluvial, the sandy ridges as levee and channel deposits, which have suffered some aeolian reworking, with source-bordering sand dunes which tend to be concentrated at the major breaks of slope between one terrace and another. Swamps and other extensive poorly drained areas, which are common on the flats between the sandy ridges, would then be interpreted as delta flood plain swamps (Figs 4, 5).

In the contrasting south-western sector of the Victorian coast, the succession of calcareous dune ridges extends from the Kanawinka scarp to the present coast and is regarded as covering most of Pleistocene time (Kenley 1971, 1976). Kenley pointed out evidence, in the truncation of some dunes, of periodic readvance of the sea, and as already mentioned, the ridges are tilted towards the north-west.

In the contiguous region of South Australia, a recent detailed traverse (Cook *et al.* 1977) has also indicated that uplift during the Pleistocene, combined with eustatic sea level changes, has produced an essentially regressive sequence resulting in a seaward progradation of about 100 km during the last 690 000 years. It was also shown that periodic readvance occurred and that the Pleistocene earth movements were partly related to the Mt. Gambier-Mt. Burr volcanicity. The last point has been largely neglected as far as Victoria is concerned but it is reasonable to expect that the late Quaternary highly explosive, although short-lived activity, such as that around Warrnambool,



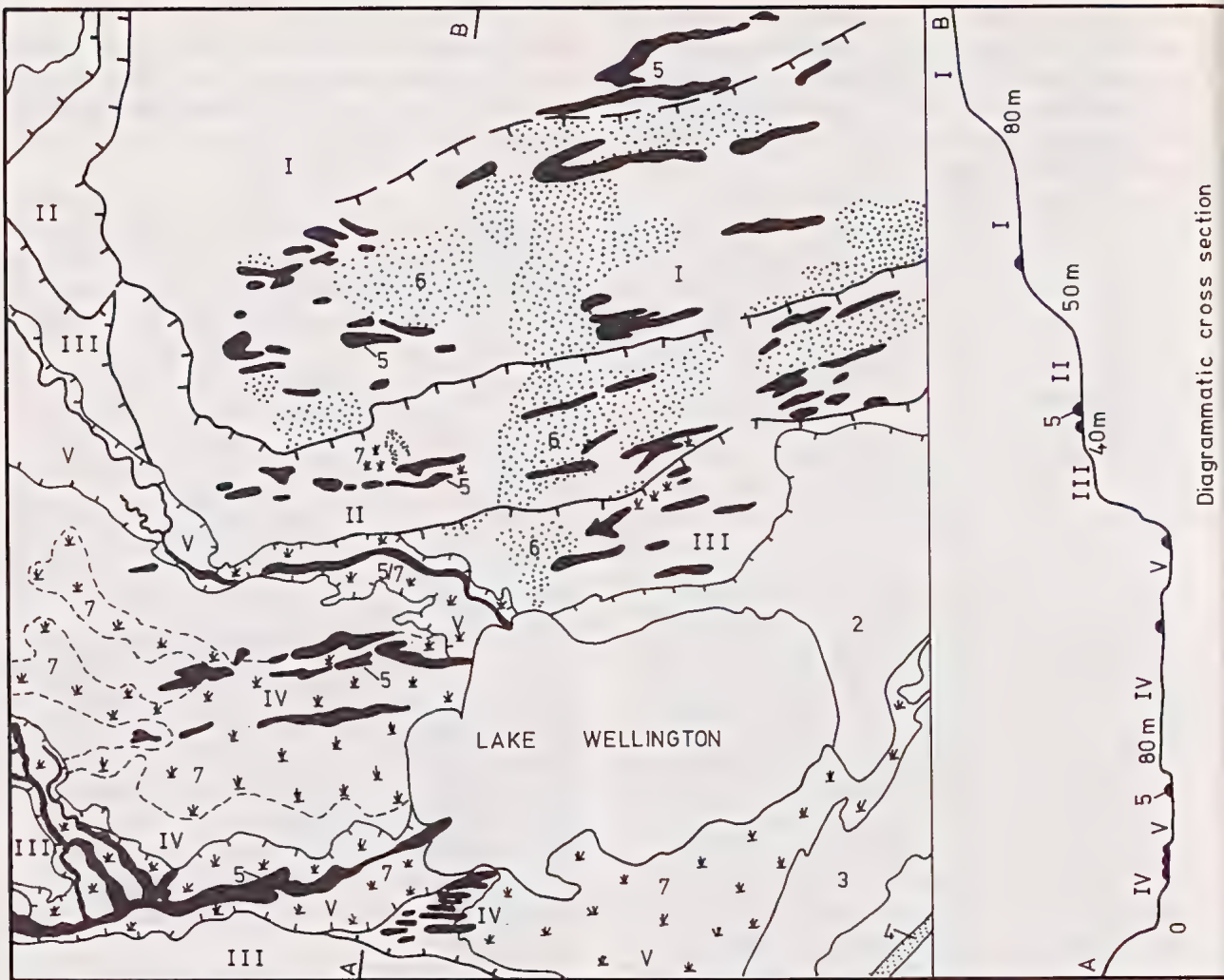


FIG. 5—Terrace sequence near Lake Wellington, East Gippsland:

I to IV, and I' to 4—as in Fig. 4; V, Contemporary flood plains and back swamps; 5, Contemporary levees and probable Pleistocene levees; 6, Sand ridges, hummocks and sheets of various ages and origins; 7, Swamps. North is to the right. Section A-B is about 40 km.

as well as earlier Pleistocene volcanic events, for example the extrusion of the Yangery (1 950 000 yr BP) and Woodbine (300 000 yr BP) Basalts, would have resulted in some earth movement. In broader terms, the remarkable coincidence of the Australian Cainozoic volcanic provinces with the overall tectonically positive Eastern Highlands (Ollier 1978) and, specifically, the late Cainozoic "areal" province of Victoria and South Australia, suggests a general association with uplift.

Further evidence of vertical uplift during the late Quaternary comes from Tasmania where marine deposits, dated as "Last Interglacial", that is during the last period of high sea level before the Holocene marine transgression, and aged by reference to their relationship with  $C^{14}$  dated non-

marine deposits, lie at 20 to 30 m above present sea level. This is 10 to 20 m higher than deposits of similar age in supposed stable areas in Australia (Van de Geer *et al.* 1979).

## CONCLUSIONS

The history of the Victorian coast can be traced back to the Late Cretaceous, but it is only from the Mid Miocene onwards that it can be documented in any detail. The coastal zone has continually migrated back and forth within the region lying between the continental slope and the upland front.

The coastal zone has been subject to sea level fluctuation, probably both glacio- and tectono-eustatic, and to broad crustal warping coupled

with local differential earth movements. In Victoria there seems little doubt that eustatic and tectonic factors have both been involved in variations of apparent sea level at any particular site. No area can be assumed to be tectonically stable, even within the broad limits imposed by the largest suggested Quaternary high sea level.

Sequences of Quaternary sea level changes and coastal stratigraphy, for example those developed in Europe and North America, should not be regarded as standard sections into which local occurrences must be fitted. Recent work on deep sea cores and on the dating of raised coral reefs promises to produce a standard sequence of wide applicability. A reliable standard such as this is necessary in the evaluation of tectonic effects on both regional and local scales.

The Tertiary is characterised by coastal advance until the Mid to Late Miocene, followed by regression during the remainder of the period. In detail, both trends included lesser marine incursions and regressions. These fluctuations were not uniform everywhere, being influenced by local structure, by tectonic activity and by the magnitude and direction of regional supergene forces.

Except in far south-western Victoria, it is probable that the Quaternary coast has rarely, if ever, been located inland far beyond the present shore. To explain this limitation, in the light of the elevation of undoubted Pleistocene marine sediments, uplift in some areas of at least 30 m is required.

On the southern Australian coast Holocene shell beds have undoubtedly emerged, but there are no equivalents on the northern NSW or southern Queensland coasts, showing that differential earth movement has been involved.

But this, in itself, does not indicate the sense of the movement. It seems that the south was more tectonically active than the north, suggesting that the southern Australian Holocene stranding was due to tectonics rather than a fall in absolute sea level. Although local earth movements appear to be mainly vertical, east-west transcurrent movement between Victoria and Tasmania is possible.

Certain features in south-eastern Gippsland, previously attributed to shallow marine and shore zone activity, can be interpreted as fluvio-deltaic erosional and depositional forms. Despite this, they would have formed close to their contemporary sea level, which implies that this level must have been, at some stage in the Early Pleistocene, at least 80 m higher than at present, that the land has been elevated by a similar amount, or that both effects, while of lesser magnitude, acted in concert.

Ridges associated with late Tertiary shorelines are not confined to the north-west and have been identified with reasonable certainty in several parts of southern Victoria. In some areas, distinct parallelism of lateral drainage is thought to have been controlled by stranded coastal ridge and trough terrain.

Many problems regarding Victorian coastal evolution remain to be solved. The principal future needs include absolute dating, to the stage when the reliability of dates for critical horizons is established, detailed studies of sedimentary facies and associated landforms over the whole of the coastal zone as it migrated through time, and a reliable stratigraphic scale with which to compare local sequences. In addition, accurate, detailed and repeated altimetric surveys are required to determine the precise levels of features described or dated and to detect neotectonic movements, which are likely to be significant along coasts such as those of south-eastern Australia.

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## THE VEGETATION OF THE VICTORIAN COAST

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**ABSTRACT:** The structure and floristics of the major Victorian coastal plant communities are described, and their distribution related to coastal physiography and lithology. The impact of Aboriginal and European man on coastal vegetation is assessed, and the importance of conservation of the coastal flora for fauna conservation, shoreline stabilization, scientific and educational purposes, and as a recreation resource is discussed.

### INTRODUCTION

The coastline of Victoria extends for some 1600 km and provides many diverse plant habitats, including cliffs, beaches, dunes, estuaries, lagoons and swamps. Changes in the orientation of the coast provide variations in aspect and a range of exposures to the prevailing westerly to south-westerly winds and salt spray. Mean annual rainfall varies from 500 mm on the western shores of Port Phillip to over 1000 mm in the Otway Ranges and at Wilson's Promontory (Turner, Ashton & Bird 1968). Variations in lithology, geomorphology, tidal amplitude and salinity further contribute to the diversity of coastal habitats.

The plant communities are discussed according to the physiography and geology of their habitats. Plant nomenclature follows Willis (1970, 1972); structural classification of the communities is based on Specht (1970).

### VEGETATION OF THE CLIFFS

Along the cliffed sectors of Victoria's coastline, vegetation varies in response to a number of factors including lithology, exposure to salt spray and prevailing winds, and cliff morphology. Structural characteristics of the rock material and degree of exposure to strong wave action influence the development of the cliff profile, and consequently the pattern of vegetation on the cliff face. On plunging cliffs such as those at the southern tip of Wilson's Promontory, vegetation is restricted to cliff-tops and occasional crevices; similarly where cliffs are vertical, plants only grow on ledges and in cracks. On more gently sloping cliffs, there may be sufficient soil to support a prolific growth of shrubs and trees. Cliffs cut in poorly con-

solidated materials, such as the Tertiary sediments of the Otway region, frequently have terraced profiles where large scale slumping has occurred. Small perched swamps sometimes form behind the lips of these slumps.

The structure of cliff-top vegetation is also influenced by the nature of the parent material; cliffs cut in granite, sandstone or limestone support shrub growth, whereas on basalt, tussock grassland is common. Some species differentiation also occurs with change in underlying rock type; although most coastal plants grow on a variety of soil types, some species occur more commonly on dune calcarenites.

The plant zonation frequently observed on cliffs is related to the ability of species to withstand damage by salt spray. Halophytic plants often occur in the zone of continual salt spray accretion immediately above high tide level, and on the cliff and cliff-tops along high wave energy sectors of the coast.

### BASALT CLIFFS

On the Portland Peninsula, cliffs cut in basalt, and overlain by calcarenite support scattered succulent species, *Salicornia quinqueflora*, *Samolus repens* and *Senecio lautis*. On the heavy clay soils of steep basalt cliffs near Flinders on the Mornington Peninsula and on Phillip Island, *Salicornia quinqueflora* and *Disphyma blackii* are found in the splash zone, accompanied by *Samolus repens*, while on the gentler, upper slopes *Poa poiformis* closed-tussock grassland occurs with *Calocephalus lacteus* or shrubs of *Calocephalus brownii*. On Phillip Island the addition of nutrients to the soil from guano deposited by seabirds has resulted in



the vigorous growth of *Tetragonia implexicoma* in the penguin rookeries (D. H. Ashton pers. comm.). The cliff-tops which were once covered by open-woodlands of *Casuarina stricta*, with *Melaleuca ericifolia* on the wetter sites, have largely been cleared and sown with pasture grasses (Calder 1975). On sheltered sectors of Westernport Bay, gently sloping basaltic bluffs may have trees such as *Casuarina stricta* growing down to the shoreline. At several sites north of Point Leo where grassy dunes front low basalt bluffs, the treefern *Cyathea australis* grows beneath *Pittosporum undulatum* and *Banksia integrifolia* (D. H. Ashton pers. comm.).

#### LIMESTONE AND SANDSTONE CLIFFS

The Tertiary limestone cliffs of the Port Campbell coast support few plants on their unstable vertical faces. Suitable sites within the splash zone may be occupied by *Salicornia quinqueflora*, *Calocephalus brownii*, *Carpobrotus* sp. and *Senecio lautus* wherever the slope of the cliff permits. Cliff-top shrubs include *Leucopogon parviflorus*, *Olearia axillaris*, *Alyxia buxifolia*, and *Helichrysum paraliu*. These low open-shrubland communities are more extensive where wind-blown sands have accumulated as cliff-top dunes, for example behind Crofter's and Martyr's Bays. Elsewhere the cliff-tops are usually covered by low heaths which are severely wind-pruned and affected by salt; in winter they are frequently waterlogged. Groves of *Casuarina stricta* and *Eucalyptus obliqua* occur within the heaths, and *Leptospermum myrsinoides* and *Casuarina paludosa* are locally dominant species. In some places the heaths extend to the edge of the cliff. Grazing has severely modified the vegetation of unprotected sectors of this coast; at Flaxman's Hill, *Acrotriche affinis*, *Banksia marginata* and *Correa reflexa*, remnants of a more extensive heath, are found with *Alyxia buxifolia*, *Calocephalus brownii* and *Leucopogon parviflorus* on the cliff edge.

Heaths also occur on other cliffed sectors of Tertiary sediments (mainly sandstones and clays with some limestones) on the Victorian coast. Cliffs cut in sandstones and clays along the Otways coast are characterised by slump terraces, which may be covered by a closed-scrub of *Leucopogon parviflorus* and *Leptospermum juniperinum*, sometimes with *Pultenea daphnoides* and occasional clumps of *Casuarina stricta*. *Phragmites communis* is frequently found in swampy basins and seeps within the slumps. On the cliff-top,

heaths grow on very infertile highly acidic soils; *Leptospermum juniperinum* and *Leptospermum myrsinoides* are often co-dominant, and occur with *Casuarina pusilla*, *Gahnia radula* and many other species (Parsons, Kirkpatrick & Carr 1977). Stunted *Eucalyptus baxteri* and *Eucalyptus nitida* are found occasionally in the heath.

In the Anglesea district, coastal heaths are found on cliffs cut in Tertiary sands and clays. These low closed-heaths, dominated by *Lepidosperma congestum*, *Leptospermum myrsinoides* and *Casuarina pusilla*, grade into a low woodland of wind-pruned *Eucalyptus obliqua* with a tall heath understorey. Cliff-top vegetation on the Tertiary sandstones on the eastern shoreline of Port Phillip is predominantly a closed-scrub of *Leptospermum laevigatum*, with *Casuarina stricta*, *Myoporum insulare* and *Leucopogon parviflorus* on cliff-top dune deposits.

In eastern Victoria between Mallacoota and the Benedore River, heaths are found on exposed and seasonally water-logged coastal plateaux where Palaeozoic sandstones are overlain by a thin veneer of Tertiary clayey sands (Pl. 5, fig. 1). Several types of heath community occur here, *Casuarina paludosa* closed-heath, *Melaleuca squarrosa*-*Leptospermum juniperinum* closed-heath, and *Xanthorrhoea resinosa* closed-heath; *Eucalyptus baxteri* and *Eucalyptus gummiifera* form mallee clumps within the heath (Cameron 1973). At some sites there is a cliff-top fringe of *Leptospermum laevigatum* or *Melaleuca armillaris* closed-scrub.

Other exposed cliff-top sites which support heaths include the Cretaceous felspathic sandstone coast of the Otways and the Devonian metamorphic rocks of Cape Liptrap. At Cape Liptrap where quartzose dune sands overlie hard sandstones, *Leptospermum laevigatum* dominates the tall heath community of the cliff-tops, whilst wet heaths of *Melaleuca squarrosa*, *Calorophus lateriflorus*, *Leptospermum juniperinum* and *Selaginella uliginosa* occur where a perched hardpan layer 10-20 cm beneath the soil surface impedes drainage. In the Otways wet heaths occur on windswept sites where species such as *Melaleuca squarrosa*, *Sprengelia incarnata*, *Casuarina paludosa*, *Epacris lanuginosa* and *Gymnoschoenus sphaerocephalus* are common (Parsons *et al.* 1977). The steeply plunging cliff faces support few plants, but on protected sites along the eastern flank of the Otways, steep coastal slopes are vegetated by shrub species including *Leptospermum juniperinum* almost down to the back of the shore platform.



## PLATE 5

FIG. 1—Cliff-top low heath east of Little Rame Head, East Gippsland.

FIG. 2—(a) Fringing *Avicennia marina* with (b) *Arthrocnemum arbusculum* and *Salicornia quinqueflora* herbfield backed by a narrow zone of *Melaleuca ericifolia*. Sandy ridges landward of the salt marsh are dominated by *Eucalyptus viminalis* woodland.

FIG. 3—*Phragmites communis* closed grassland fringing Lake Connemare.





*sifolia* (not found elsewhere in Victoria); in the Otways and at Princetown *Acacia longifolia* and *Leucopogon parviflorus* form a closed-scrub on dune sands, but *Melaleuca lanceolata* is absent. *Melaleuca lanceolata* is co-dominant with *Acacia retinodes* on dune calcarenite at Point Roadnight near Anglesea, and these species together with *Leptospermum laevigatum*, form closed-scrubs at Mt. Coolite near Barwon Heads, and on the Nepean Peninsula. *Melaleuca lanceolata* does not extend further east than Corinella (Willis 1948). Figure 1 shows the distribution of *Leptospermum laevigatum* and *Melaleuca lanceolata* on the Victorian coast.

#### GRANITE CLIFFS

Plunging granite cliffs and rocky headlands usually support a closed-scrub of *Leptospermum laevigatum* and associated species. On the west coast of Wilson's Promontory the lichens *Verrucaria* sp. and *Caloplacca marina* are found just above high water mark and *Disphyma* sp. and *Salicornia* sp. occur within the splash zone. Above the splash zone are wind-pruned shrubs of *Correa alba* and *Calocephalus brownii*, with a closed-scrub of *Leptospermum laevigatum*, *Pultenea daphnoides* and *Kunzea ambigua* on shallow gravelly loams further upslope (D. H. Ashton pers. comm.). *Casuarina stricta* thickets occur above the zone of salt spray on slightly deeper soils, together with *Kunzea* and *Leptospermum* (Parsons 1966).

On rocky granitic headlands of the East Gippsland coast *Stipa teretifolia* tussock grassland (with *Distichlis distichophylla* and herbs such as *Apium prostratum*, *Scaevola calendulacea*, *Disphyma australe* and *Carpobrotus rossii*) fringes exposed western and southern shores. Where dunes surmount headlands the dune slopes carry wind-pruned low heaths of *Correa alba*, *Banksia integrifolia*, *Monotoca elliptica* and *Leptospermum laevigatum*. More sheltered slopes support a taller closed-scrub of the last 3 species and *Melaleuca armillaris* (Smith & Parr-Smith in press).

The windswept granite headlands of Cape Woolamai (on Phillip Island) support *Poa poiformis* and *Stipa teretifolia* tussock grassland, with shrubs on less exposed sites (Teh 1966). On Rabbit Island, off the east coast of Wilson's Promontory, *Poa poiformis* is the dominant species (Norman 1967). However since the decimation of the rabbit population in 1965, shrub species such as *Leptospermum laevigatum*, *Leucopogon parviflorus* and *Correa alba* are re-establishing here (Pl. 6, fig. 5).

#### VEGETATION OF SALT MARSHES AND SWAMPS

Extensive intertidal plant communities occur in sheltered situations along low wave energy sectors of the coast, in embayments, along the lower reaches of estuaries and estuarine lagoons, behind barrier islands and in the lee of spits (see Fig. 2). Variations in salinity, water depth, extent and duration of tidal submergence and nature of the substrate (which may be mud, sand, gravel or rock), influence the distribution of these intertidal communities. In response to these factors, plants commonly grow in zones parallel to the shore. Within estuaries and estuarine lagoons changes in the vegetation occur as tidal influence and salinity levels diminish with increasing distance from the sea.

Salt marshes are best developed between Barwon Heads and Corner Inlet, their lateral extent being related to the relatively large tidal ranges experienced along this part of the coast. The marshes are frequently fringed by *Avicennia marina* var. *resinifera* (Fig. 2, Pl. 6, fig. 6), which has its southern most occurrence at 38°55' in Corner Inlet (Bird 1972). West of Barwon Heads, patches of salt marsh are found at Breamlea, at the mouth of the Anglesea River and Airey's Inlet, at Port Fairy, and in the Glenelg River estuary. Salt marshes also fringe shorelines within the Gippsland Lakes, and are thought to have become more extensive following a salinity increase resulting from the cutting of the artificial entrance to the lakes (Bird 1962). Along the East Gippsland coast salt marshes are found at Wangan Inlet, Mallacoota, and the mouth of the Snowy River.

Many of the salt marsh plants found in Victoria belong to the family Chenopodiaceae, whose members frequently have succulent foliage, and are well adapted to saline conditions. The genera *Salicornia*, *Arthrocnemum*, *Suaeda*, *Samolus*, and *Triglochin*, found in Victorian salt marches are cosmopolitan. Some species, such as *Selliera radicans* and *Wilsonia* spp. are typically Australasian in distribution (Bridgewater 1975). The number of species occurring within the salt marsh is not large, the total number of salt marsh species present in Western Port being 49, including introduced plants.

Victorian salt marshes show some regional variations in their structure and floristics. Common communities include tall shrubland or open-scrub of *Avicennia marina*, *Arthrocnemum* spp. low shrubland, *Stipa teretifolia*-*Juncus maritimus* open-tussock grassland, sedgeland, and herbfields frequently dominated by *Salicornia quinqueflora*.



*Melaleuca ericifolia* closed-scrub is often found above maximum high tide level on the landward side of the salt marshes. However, not all these communities may be represented at a particular locality.

Many of the species found in the highly developed salt marshes of Western Port do not commonly occur in other Victorian salt marshes; the shrubby *Arthrocnemum* species are not found east of The Lakes National Park (Sperm Whale Head), and only occasionally west of Breamlea near Barwon Heads. In East Gippsland, salt marshes are of limited occurrence and have few species. At Wingan and Mallacoota Inlets salt marshes are reduced to *Juncus* open-tussock grassland and *Salicornia* herbfield, with only 4 or 5 species present. A decrease in the number of species present is also observed in western Victorian salt marshes (Barson 1976).

In many Victorian salt marshes the characteristic zonation of halophytes parallel to the shore is complicated by small changes in marsh level. Such minor topographic variations may be related to the development of pans and tidal creeks, or the deposition of sandy or shelly cheniers on a generally muddy substrate. Differences in level of a few centimetres may favour the establishment of a particular species over another. The salt marshes behind Observation Point on Phillip Island show a particularly complex species distribution pattern due to the presence of veneers of sandy sediment across the marsh. Within the marsh, stranded sandy ridges, common in the salt marshes of Western Port and at Barwon Heads support a community dominated by *Stipa teretifolia*, a species not common elsewhere in these marshes.

A distinction may be made between 'wet' and 'dry' salt marshes in Victoria. The wet form is typified by salt marshes around Western Port, where the average annual rainfall is 800 mm. Landward of the mangrove fringe are zones of *Arthrocnemum arbusculum* low shrubland and herbfield of *Salicornia quinqueflora* with *Suaeda australis*, *Selliera radicans*, *Samolus repens* and *Hemichroa pentandra* as frequent components. These often fade into a zone dominated by grasses such as *Distichlis distichophylla*, sedges and rushes such as *Juncus maritimus*, with occasional small, unvegetated salt pans in front of *Melaleuca ericifolia* closed-scrub (Pl. 5, fig. 2). Climax vegetation was probably *Eucalyptus viminalis*-*Eucalyptus ovata* woodland with *Melaleuca ericifolia* and a sedge stratum, but most of this stage has been removed by clearing (Ashton 1972).

Along some sectors of the Western Port shoreline, *Eucalyptus viminalis* woodland grows on low sandy ridges landward of the *Melaleuca* thickets.

'Dry' salt marshes are found on the west coast of Port Phillip, where average annual rainfall is 500 mm or less. Mangroves which once fringed some sectors of this coast are now largely restricted to Limeburner's Bay and Williamstown. Extensive zones of *Arthrocnemum arbusculum* are common, sometimes with a scattered understory of succulent herbs; towards the landward limits of these marshes there is frequently a broad zone of salt pan (dry in summer, inundated in winter), supporting *Frankenia pauciflora* and scattered *Arthrocnemum halocnemoides*, a species which forms extensive communities on South Australian salt marshes (Specht 1972). According to Ashton (1972), the climax stage was probably a grassy *Muehlenbeckia cunninghamii* scrub, perhaps with occasional *Eucalyptus camaldulensis*, but this too has been obliterated by clearing.

As tidal influence decreases towards the upper reaches of estuaries and estuarine lagoons, halophytic species are replaced by fresh or brackish water plant communities; reed swamps and closed-scrubs. A zone of *Phragmites communis* (Pl. 5, fig. 3) sometimes in association with *Typha* spp., fringes such fresh and brackish water environments, but east of the Snowy River only scattered small clumps of *Phragmites* are found around the shores of lakes and estuaries, the reed swamps (principally around lakeshores) being dominated by such species as *Baumea rubiginosa*, *Cladium procerum* and *Eleocharis sphacelata*.

Landward of the reed fringe on areas still prone to flooding, are closed-scrubs, dominated either by *Melaleuca ericifolia* or *Leptospermum lanigerum* depending on the location of the site. *Melaleuca ericifolia* is thought to be restricted in Victoria to swampy sites east of the You Yangs (J. Ladd pers. comm., Fig. 1), while in western Victoria, *Leptospermum lanigerum* forms closed-scrub around some lake shorelines and along rivers. *Melaleuca lanceolata* occurs on swampy sites at the mouth of the Anglesea River and along the Barwon, but throughout the rest of its range it is a species of elevated, well-drained sites (Parsons et al. 1977).

The presence of reedswamps around the shores of lagoons and some estuaries is contributing to the gradual infilling of the sites. Submerged pondweeds (commonly *Potamogeton* and *Vallisneria* in fresh, and *Zostera* in brackish water) build up the level of the floor by adding debris and collecting silt, to a depth where reed and sedge species can

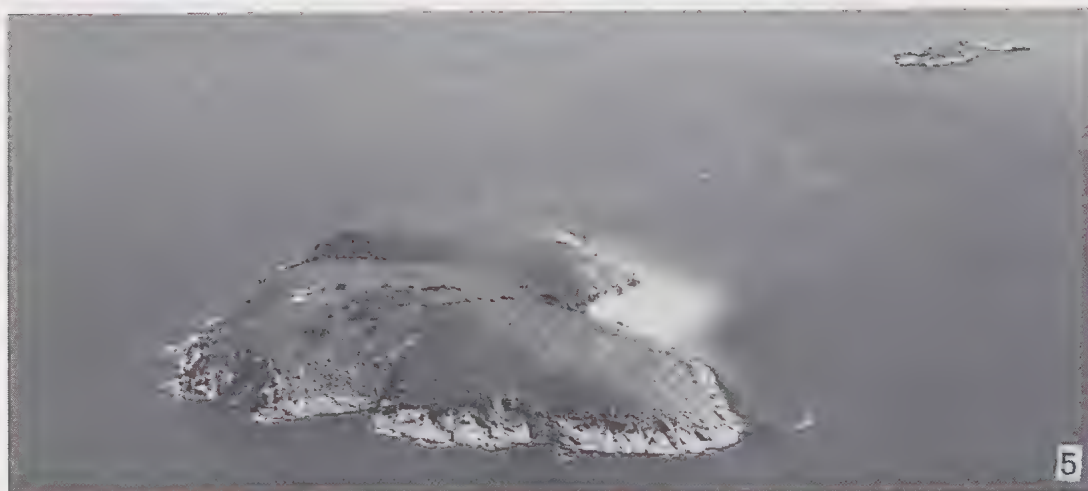


PLATE 6

FIG. 4—Closed scrub of *Leptospermum laevigatum* and *Banksia integrifolia* east of Point Hicks, East Gippsland.

FIG. 5—*Poa poiformis* tussock grassland, Rabbit Island, east of Wilson's Promontory.

FIG. 6—*Avicennia marina* on the Lower Barwon River.



invade. Sedimentation within the reed fringe further reduces water depth, allowing invasion by swamp scrub species, *Melaleuca ericifolia* or *Leptospermum lanigerum* (Bird 1962). This process of encroachment succession is accelerated at several sites along the coast where sand from mobile dunes is invading estuaries and lakes. However, increased salinity levels in some parts of the Gippsland Lakes have resulted in dieback of shoreline *Phragmites* and erosion of land previously created by encroachment of reed swamps which died following the cutting of the artificial entrance in 1889 (Bird 1961a).

### SAND DUNE VEGETATION

Along the Victorian coast, sand dunes are found in Discovery Bay, Waratah Bay and Port Phillip, from Point Lonsdale to Lorne, along the Ninety Mile Beach, on sectors of the East Gippsland coast, and in pockets along the cliffed coastlines of the Otways, Wilson's Promontory and Phillip Island. Dunes east of Wilson's Promontory are predominantly of quartzose sand; those to the west are dominated by calcareous sand (Bird 1976).

A characteristic vegetation zonation occurs where successive dune ridges have formed parallel to the shoreline as in sectors of the outer barrier behind the Ninety Mile Beach. This zonation reflects the succession of vegetation types from the pioneer colonising species (typically grasses) on the foredune, through shrub species to a dune scrub, with woodland or even heath on the older ridges. Extensive rearrangement of parts of older parallel dune systems, as on Sperm Whale Head, has resulted in secondary succession; the parabolic dunes carry younger soils and dune scrub vegetation, whereas the undisturbed parallel ridges are covered by heath or woodland (Bird 1961b). Behind Norman Bay at Wilson's Promontory the older parabolic dunes with acid soils are heath covered, and the more recent parallel dunes support a dense scrub (Parsons 1966).

Most of the common species associated with sand dunes are found all along the coast, exceptions being those particularly associated with highly calcareous sands, and several scrub species of restricted occurrence in Victoria. The earliest colonisers of sandy shorelines above high tide level are the strand plants, *Cakile* spp. and *Atriplex cinerea*. Plants of the foredune are initially grasses, *Spinifex hirsutus*, occasionally *Festuca littoralis*, and the introduced species *Ammophila arenaria* and *Agropyron junceum*. These grasses are subsequently invaded and replaced by shrub

species which may include *Myoporum insulare*, *Acacia longifolia*, *Correa alba*, *Olearia axillaris*, *Helichrysum paraliu*, *Leucopogon parviflorus* and *Rhagodia baccata* and rushes and sedges such as *Scirpus nodosus* and *Lepidosperma gladiatum*. However sandy shorelines in Victoria are generally receding and examples of primary succession on newly-built beach ridges and foredunes are restricted to a few localities, chiefly on spits and cusped forelands and alongside sand-trapping breakwaters (Bird 1973).

Landward ridges support dune scrub; in eastern and central Victoria this is frequently dominated by *Leptospermum laevigatum* (see Fig. 1) with emergent *Banksia integrifolia* (Pl. 6, fig. 4). Where *Leptospermum* forms a dense canopy the understorey species are mainly mosses such as *Hypnum cupressiforme* and *Thuidium furfurosum*, orchids, chiefly species of *Acianthus*, *Caladenia*, *Corybas* and *Pterostylis*, herbs and climbers such as *Clematis microphylla*, *Muehlenbeckia adpressa* and the introduced *Asparagus asparagoides*. In more open degenerate stands dune shrub species may form an understorey, whilst on some calcareous dunes *Acacia retinodes* and *Melaleuca lanceolata* may be co-dominant with *Leptospermum laevigatum*. *Leptospermum laevigatum* is only known to occur sporadically west of Barwon Heads (Parsons *et al.* 1977), and at some of these sites it may have been planted. In western Victoria, *Leucopogon parviflorus* forms a low closed-scrub on dunes, sometimes in association with *Melaleuca lanceolata* and *Acacia longifolia*.

Older dunes with more deeply leached soils usually support eucalypt woodlands, but on exposed or severely waterlogged sites these sandy areas are frequently heath covered. On dune sands and sand sheets along the East Gippsland coast between Wingan Inlet and Little Rame Head *Eucalyptus gummifera*-*Angophora floribunda* woodlands occur, with a mosaic of *Casuarina paludosa*-*Leptospermum juniperinum* or wet heath communities, *Melaleuca ericifolia* scrub, sedges and rushes. Similar heaths are found along the coast from Rame Head to Lake Tyers, with *Eucalyptus botryoides*-*Eucalyptus baxteri* woodlands (Land Conservation Council 1974). *Eucalyptus viminalis* woodlands with *Banksia serrata*, *Eucalyptus radiata* and *Eucalyptus bridgesiana* occur on dunes behind the Ninety Mile Beach, with some areas of *Eucalyptus nitida* woodland (Land Conservation Council 1972). *Eucalyptus viminalis* also forms dune woodland with *Banksia serrata* on the barrier islands southwest of the Ninety Mile Beach (Turner, Carr

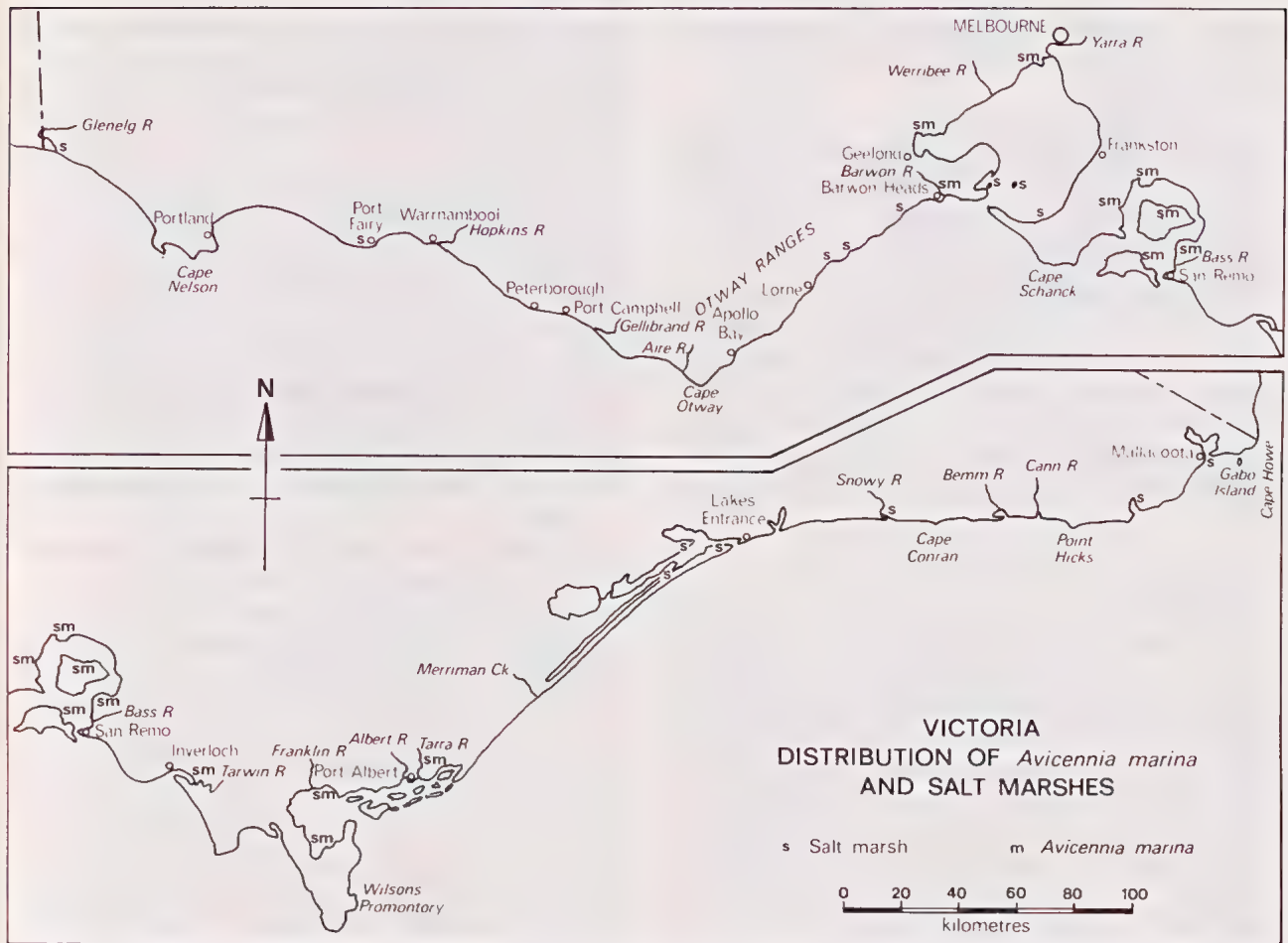


FIG. 2—Distribution of *Avicennia marina* and tidal, salt marsh communities along the Victorian coast.

& Bird 1962), and on older sandy ridges around Western Port and Port Phillip. Where dune woodland occurs on sites west of Port Phillip, it is often dominated by *Eucalyptus obliqua*.

#### THE IMPORTANCE OF COASTAL VEGETATION

Vegetation is an important agent in the building and stabilization of some coastal landforms. On prograding sandy sectors of the Victorian coast dune building is initiated by grasses such as *Spinifex hirsutus* or the introduced *Ammophila arenaria* (marram grass), and sometimes by the annual *Cakile* spp. These plants trap blown sand, building hummocks, ridges or terraces which may persist as foredunes. The establishment of a new beach ridge in front of the foredune cuts off the sand supply to its successor which becomes relatively stable when the dune grasses are invaded by shrub species. Dune scrub provides sufficient cover to stabilize unconsolidated sands, but subse-

quent destruction of this cover results in the development of blowouts which may advance inland.

Mangroves and salt marshes also play a role in shoreline stabilization, trapping sediment which would otherwise remain mobile on the intertidal flats. These communities reduce the need for dredging to maintain channels and harbour facilities.

Dune scrub, heaths and salt marshes provide habitats for a wide variety of wildlife, some of which is restricted to coastal areas. One of the world's rarest parrots, the orange bellied parrot (*Neophema chrysogaster*) has been recorded from several coastal localities in Victoria, while the uncommon ground parrot (*Pezoporus wallicus*) is found only in coastal heaths in south-eastern Australia (Johnson 1974). The Victorian coastline is also a natural migration route for many species of waders and seabirds, and our coastal marshes are particularly important as feeding grounds and



refuges for waders (Dorward 1976). Mangrove swamps are also important as fish nurseries and breeding grounds.

The vegetation of the coast is of considerable botanical interest, particularly since changes within communities may be comparatively rapid and thus provide opportunities for detailed monitoring. Comparatively undisturbed sites are of special importance since so much of the coast has been modified to some extent by the activities of man. Rare or uncommon species such as *Asplenium obtusatum* and *Cyathodes oxycedrus* are known from several cliff communities, while the coastal heaths of East Gippsland (Cameron 1973) and Port Campbell (A. C. Beauglehole pers. comm.) support a number of species of limited occurrence.

### THE IMPACT OF MAN ON COASTAL VEGETATION

The vegetation of a large area of the Victorian coast has been severely modified by the activities of man. The coast has been and will continue to be subject to severe pressures due to recreational, residential and rural demands. These demands have resulted in alteration and sometimes complete obliteration of coastal plant communities.

The abundance of archaeological sites along the Victorian coast indicates extensive Aboriginal utilisation of coastal resources. The Aborigines' use of fire to drive out game, or to burn grass to attract fresh game to shoots, and their apparently careless use of campfires (King 1963) probably led to an increased incidence of bushfires in the region.

The practice of frequent burning to provide pasture has been continued along some sectors of coast until quite recently, notably in East Gippsland and the Western District. On dune terrain repeated grazing and burning has in some areas resulted in the development of blowouts, some of which have subsequently been stabilized by planting marram grass. Dune scrub between Portland and Warrnambool has now been largely replaced by marram grass, but a few relict stands remain on sites which have escaped grazing and burning. Along the northern shores of Western Port and east of San Remo coastal vegetation has been almost completely replaced by pasture.

Urban expansion and the development of coastal sub-divisions have also resulted in the disappearance of extensive tracts of coastal vegetation. The spread of Melbourne's south-eastern suburbs has led to the reduction of coastal heathlands, which prior to settlement extended

south from the Yarra River to Mordialloc and east to Springvale (Anon. 1976). Most attempts to conserve the remaining fragments of this heath vegetation on suburban blocks have been unsuccessful, because *Leptospermum laevigatum* has displaced most of the heath species.

Subdivision of coastal dunes along parts of the Ninety Mile Beach and at Point Smythe has alienated large tracts of dune scrub. The construction of roads parallel to the coast has in many areas reduced coastal vegetation to a narrow strip of Crown Land Reserve, and provided easy access which has in turn led to damage by trampling, erosion and rubbish dumping. The large boundary: area ratio of these reserves, many of which constitute the only remaining area of near natural bushland in an urban environment, makes management extremely difficult (Kirkpatrick 1974); such sites are very vulnerable to edge effects such as pesticide drift and invasion by weeds.

Further modification of coastal plant communities has been brought about by both deliberate and accidental introduction of exotic species, the most important being *Ammophila arenaria* which has been widely planted by coastal management authorities to stabilize dunes. Other locally common exotics include the Myrtle-leaf Milkwort, *Polygala myrtifolia* which forms dense understory thickets on parts on the Nepean Peninsula, and boneseed, *Chrysanthemoides moniliferum*. Boneseed, which can establish on very poor soils, is able to eliminate smaller native species through competition (Parsons 1973). Many other species occur as garden escapees on dunes in urban areas.

Major destruction of salt marsh and swamp communities has occurred through sanitary landfill and reclamation schemes, as at Hastings and Rhyll on Western Port and at Barwon Heads where municipal tips have been located on salt marshes (Barson 1976). The area of salt marsh has been further reduced by the development of harbour facilities, and the construction of boat jetties and marinas has been an important factor in the disturbance of intertidal communities in Western Port (Bird & Barson 1975). The increasing use of recreational vehicles on salt marshes is also a cause for concern.

The use of the coastal zone as a recreational resource has resulted in the modification of many coastal plant communities. In urban areas, for instance, as along the shores of Port Phillip, coastal land has been cleared to provide sites for sporting grounds and club houses (some of which serve activities that are not dependent on coastal loca-



tions), access roads, car parks, camping sites and other visitor facilities. In areas receiving the most intensive use, uncontrolled access has resulted in damage to the vegetation and often in subsequent erosion.

In spite of such pressures many valuable tracts of coastal vegetation persist in natural or semi-natural conditions. The provision of fencing and well-defined access tracks has helped to reduce the impact of visitors on vegetation at some sites along the coast, but many areas will require more intensive management along the lines of the Seaford Foreshore Reserve Program (Bird 1975, Thatcher & McAlpine 1975), to conserve and maintain the present diversity of coastal communities.

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## COASTAL ARCHAEOLOGY IN VICTORIA

### PART 1: THE MORPHOLOGY OF COASTAL ARCHAEOLOGICAL SITES

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#### INTRODUCTION

Of Victoria's archaeological sites those on the coast are amongst the most obvious, the most numerous, the most vulnerable to damage and potentially the richest sources of information about the prehistoric past. As an interface between the productivity of the sea and the productivity of the land, the coastal environment normally offers relatively abundant and reliable sources of food. Consequently, archaeological studies of coastal sites provide a record of settlement patterns very different from those associated with inland sites.

In Part 1 of this paper an up-to-date review of the data available from the records of the Victoria Archaeological Survey and from published documents is presented. In particular, an attempt will be made to define the various types of sites found on the coast, to indicate their distributions, to assess their states of preservation and to look at cultural variability. In Part 2, aspects of the Aborigines' adaptations to changes in coastal environments will be examined.

#### THE SOURCES

In 1975 the Town and Country Planning Board commissioned the Victoria Archaeological Survey to produce a report on coastal archaeological sites of special scientific interest in Victoria. After a short period of intensive fieldwork a comprehensive report was prepared (Coutts *et al.* 1976). It reviewed the literature on Victorian coastal sites and stressed the urgent need for more comprehensive field studies. It also documented the degree of preservation of coastal archaeological sites. Areas of the coast were classified according to their potential archaeological significance and management procedures were outlined for the most important areas. The present review uses much of the material published in that report and the reader is

referred to it for further details and a detailed bibliography.

Since 1976 more data on coastal sites have become available. Lourandos (1976) has published some preliminary comments on his excavations at Bridgewater Caves, near Cape Bridgewater and at Seal Point, Cape Otway. Willacy (pers. comm.) has been recording Aboriginal sites on Phillip Island. Hughes and Wesson (1978) carried out a survey at Point Wilson, near Geelong and Wesson and Clark (1980) have surveyed the area around Point Danger, near Portland. Surveys of coastal areas commissioned by private and government authorities cover parts of Marilyns Beach (Clark & Pickering 1978), the area between Jack Smith Lake and Lake Denison (Bell & Clark 1977, Witter *et al.* 1976) and part of the Ninety Mile Beach north-east of Loch Sport (Bell *et al.* 1977, Simmons & Irish 1977).

Archaeological surveys have been made of the coastline between Warrnambool and Yambuk, an area near Glenaire, strips of coastline between Cape Paterson and Wonthaggi, the coastal strip south of Lake Reeve, the coastline between Tamboon Inlet and Cape Everard, Gabo Island and some parts of Mallacoota Inlet (Fig. 1). During these surveys, excavations and test pits were completed at Captain Stevensons Point and Top Lake near Mallacoota, Gabo Island, and Goose Island, The Craigs, Pickering Point, Reamur Rocks, Thunder Point and Armstrong Bay in the vicinity of Warrnambool and Port Fairy, western Victoria (Coutts 1977, 1978a, Coutts & Witter 1977). Archaeological surveys of the Mornington Peninsula and the Discovery Bay area are underway at present.

#### TYPES OF COASTAL ARCHAEOLOGICAL SITES

Aboriginal sites may be classified in many ways, depending on the use to be made of the classifica-



tion. The Victoria Archaeological Survey uses a system in which environmental setting, contents, assumed functions and state of preservation are considered. Six broad coastal site types have been defined, based on a study of 647 sites from the study areas (Fig. 2).

### 1. MIDDENS

These consist of shells mixed with charcoal fragments, stone flakes, pebbles and bone in varying proportions. The deposits may vary in area and thickness. In many instances all the sediments covering the *in situ* material have been eroded and the midden material is scattered on the surface. Once these sites have been exposed they erode rapidly.

### 2. SURFACE SCATTERS

These consist of stone material, probably derived from middens which have disappeared, or from workshops where stone tools were manufactured. Evidence from this type of site is often ambiguous, since materials from different phases of occupation may be mixed through deflation. Nevertheless, many workshops have survived, and their careful assessment may enable the technological processes associated with the production of stone tools to be determined (e.g. Witter 1977).

### 3. QUARRY SITES

These sites vary in character, but normally comprise piles of debitage found near sources of raw material suitable for making stone tools. Most of these sites found in the coastal region are small in comparison with those found inland.

### 4. AXE-GRINDING SITES

These are shallow depressions formed as a result of grinding down axe blanks or sharpening axes. They are normally found on outcrops of sandstone and are rare throughout Victoria.

### 5. SCARRED TREES

These are trees from which bark has been cut. Observers frequently give functional names to these trees (e.g. canoe trees), but in many instances it is not possible to determine the reason for the bark being cut. It is also often difficult to determine if a scar has formed naturally or not.

### 6. STONE STRUCTURES

These are mostly stone alignments, found in rivers or creeks or in situations which suggest an

Aboriginal origin. Those in streams may have been used as weirs or for trapping eels and other fish (Coutts *et al.* 1978). Other alignments, on higher ground, could have served ceremonial functions or been used as habitations (e.g. Coutts *et al.* 1977).

## STATE OF PRESERVATION OF SITES

Scarred trees, and the rarer sites such as fish traps and axe-grinding grooves are, in general, fairly well preserved. Information on the state of preservation of 154 coastal middens shows that all sites have been damaged. Only 25% still have some *in situ* material, 21% have been so badly damaged that they are of little or no use for research, and the remainder are between these extremes. Surface scatters are also poorly preserved.

Over the past few years evidence for erosion of the coastline at several points has been recorded. There can be no doubt that many recent sites have already disappeared and others are threatened. Consequently, our concept of the original distribution, variety and density of recent sites may be false.

## DATING COASTAL SITES

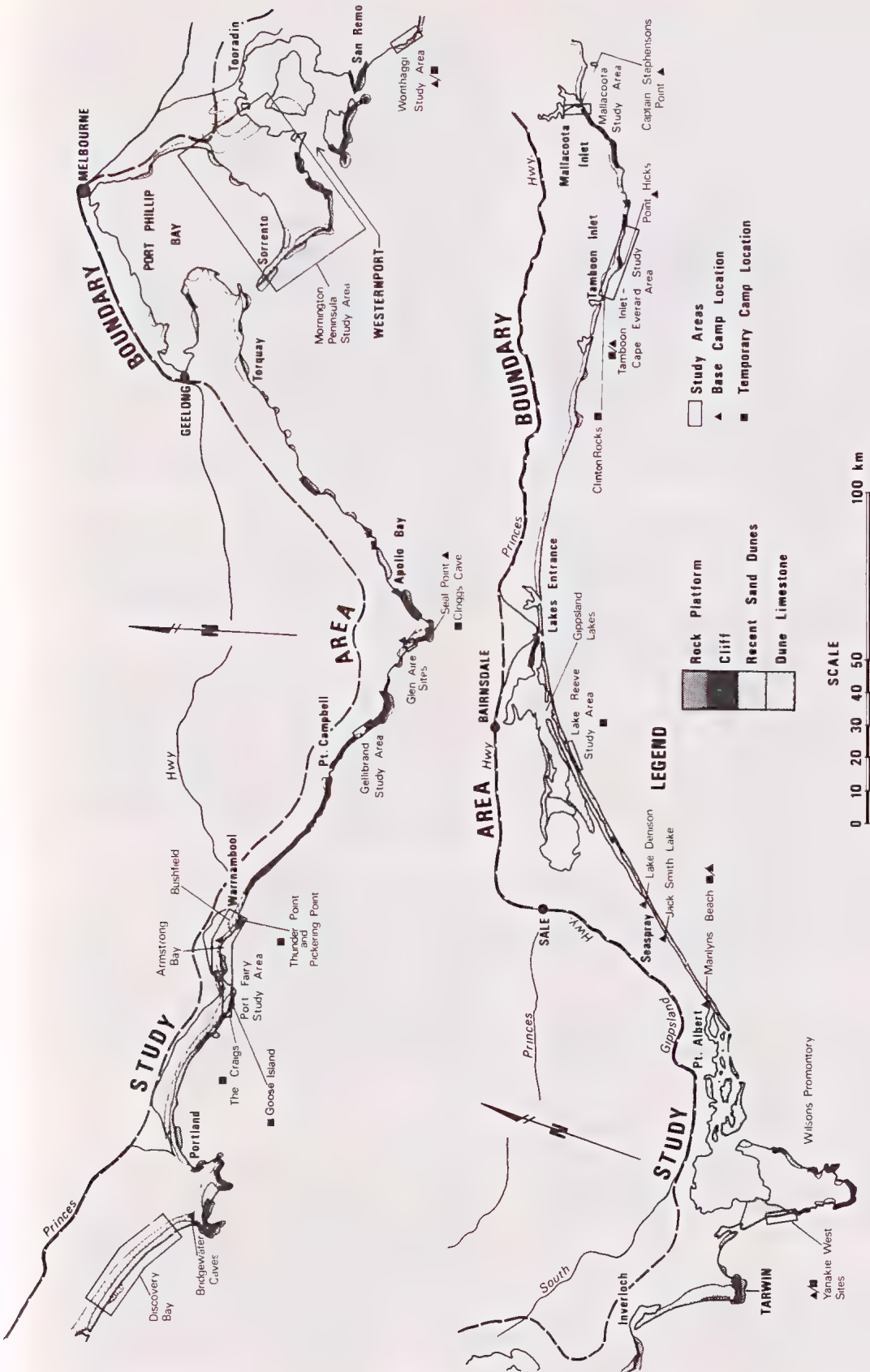
Fish traps, quarries and axe-grinding sites have not been dated at all, but many may have been in use at the end of the prehistoric period since they are still fairly well preserved. Scarred trees are difficult to date, though most cannot be older than a few hundred years. Most surface scatters can be dated only roughly from the presence or absence of certain types of key tools such as backed blades.

In general, middens along the present coastline cannot be much older than about 6 000 B.P. (when the coastline last stabilised) and most are younger. Radiocarbon dates available for Victorian coastal archaeological sites (Table 1) range from 17 000 B.P. to the present in the hinterland and from 6 500 B.P. in the foreland.

## SITE DISTRIBUTION

Natural resources of the coastal region vary greatly and it is held that their distribution will affect the type, location and relative density of archaeological sites. Further, when sites are found near several different environments, their contents will reflect this environmental diversity.

The Victorian coastal region has been classified into 14 zones (Fig. 2) (after Coutts *et al.* 1976) according to physiography of the coastline, availability of natural resources, and original



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FIG. 1 — Distribution of major foreland and littoral types and locations of sites mentioned in text



vegetation patterns. Each zone has different potential food resources associated with its major habitats (Coutts *et al.* 1976), but many of these are seasonal and their importance to Aboriginal populations at any time must be weighed against the importance of alternative food resources available in the hinterland.

Availability of other resources such as water, stone and organic materials must also be considered. For example, eucalypt bark was an important material in Victorian Aboriginal culture (e.g. Smyth 1878), so the position of eucalypt forests in relation to the foreland may have influenced campsite location. Lastly, while prehistoric populations may have had access to a variety of natural resources, they would have needed an appropriate technology to take advantage of them. For example, seaworthy craft would have been a prerequisite for offshore fishing (Lampert & Hughes 1974).

The distribution of 647 coastal Aboriginal sites is summarised in Table 2 but since only obvious and visible sites have been recorded the data are of limited value for quantitative analysis.

The locations of rarer types of sites such as axe-grinding grooves, quarries and fish traps which tend to be function specific, seem to be decided more by geographic and geological factors than the availability of food resources. Similarly, scarred trees are only found in the hinterland, as no suitable trees grow on the foreland.

Surface scatters are found in about the same proportions in both the foreland and the hinterland. Assemblages in the two areas can sometimes be distinguished on the basis of the type, variety and frequency of occurrence of artefacts in them. This distribution is not unexpected, since stone tools would have been required in both areas.

Middens are most common on cliff tops and dune systems in the foreland, since these areas are generally near food resources being exploited (Coutts 1966: 345).

To illustrate some factors affecting location of midden sites, one study region was examined in more detail (Fig. 3). The area includes 25 km of sandy coastline with 43 middens and two surface scatters. Only 10 sites have some *in situ* material left; the remainder have very little research potential.

Sixty per cent of the sites are fronted by sandy beach and in some instances the nearest rock platforms are as much as 5 km away. The rest are located near rock platforms (see Table 3). All sites (except the two surface scatters which have no

associated food refuse), have a predominance of rock platform molluscs (*Brachidontes*, *Mytilus*, *Subnina*, *Cellana* and *Dicathais*). Molluscs from sandy beaches were found at only three sites, two of which are within 100 m of both rock platforms and sandy beaches. The third site is about 2 km from the nearest rock platform. Most sites are also within easy reach of estuaries (normally less than 5 km), yet no estuarine fauna have been found in any of the sites.

Possible explanations for a predominance of rock platform shellfish include gastronomic preferences, the possibility that sandy beach shellfish were scarce in this area and preferences for shellfish species that had a high energy yield for a relatively modest energy outlay (see Table 4). All of the sites lie well within the 5-15 km considered (Gould 1969: 12, Howitt 1904: 767, Tindale 1972: 242 ff) to be the daily foraging range of hunter-gatherers (Table 3).

A similar study of data from other coastal regions confirms that most coastal midden sites are situated in sandy environments and that the preferred food resource was shellfish from rocky shorelines (Fig. 4).

## CLASSIFICATION OF MIDDEN SITES

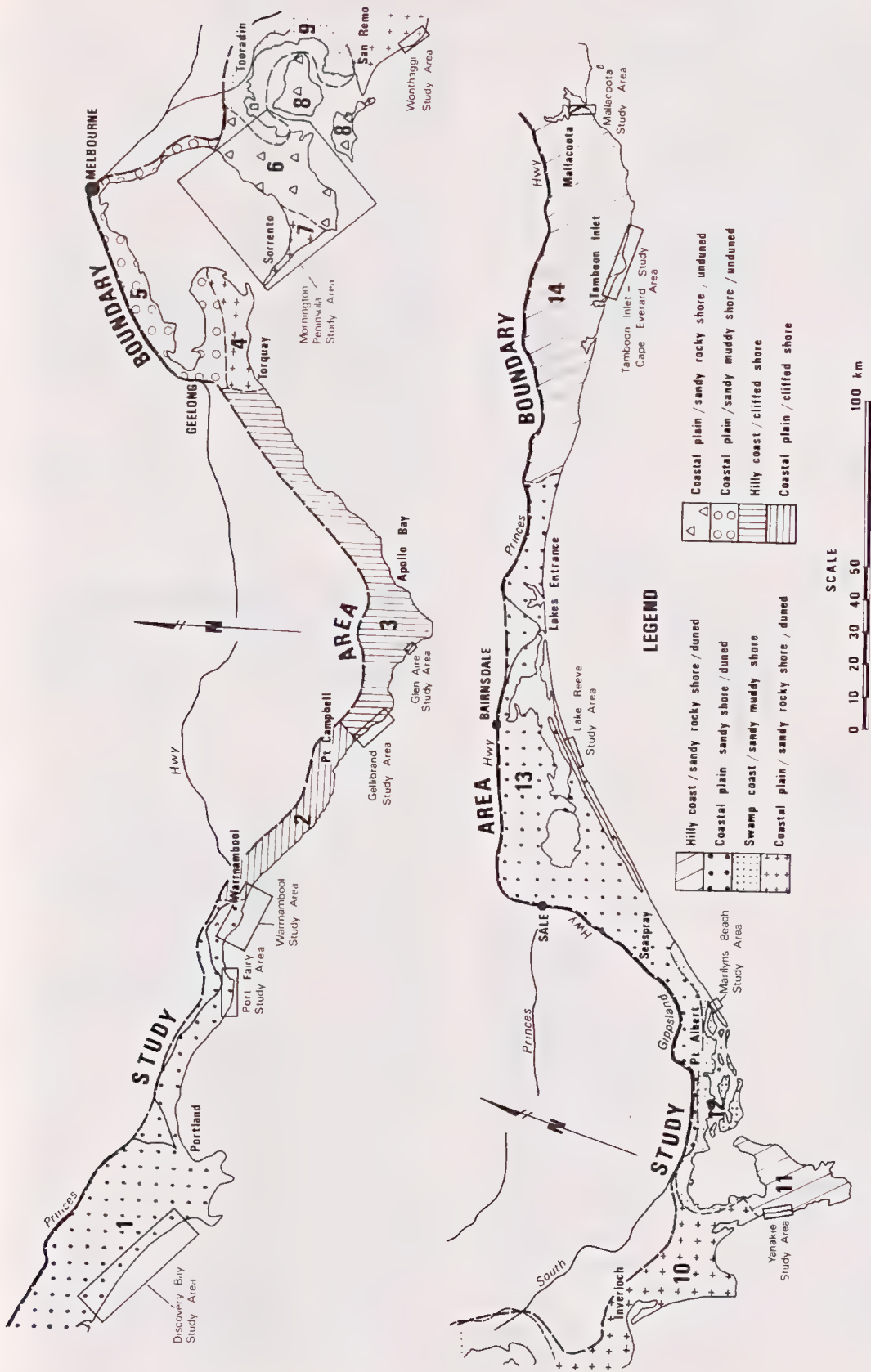
Middens result from many different activities, including bone and stone tool manufacture and butchering and cooking food. A detailed study of the contents of some of the middens and surface scatters in each of the study areas suggested four broad categories:

### 1. SHELLFISH REFUSE HEAPS

These are little more than heaps of discarded shells, with occasional flakes, charcoal and faunal remains. Such sites are function specific and occur in all environments. They were probably occupied briefly while locally collected shellfish were eaten. Typical sites include Clinton Rocks, Thunder Point and The Craigs, all of which overlook rocky shores.

### 2. BASE CAMPS

These contain the remains of shellfish and other animals, stone and bone artefacts, charcoal, hearth stones and evidence of stone tool manufacture. Such sites occur in all environments and were bases from which foragers exploited the resources of the surrounding landscape. Typical sites are found at Wilsons Promontory, Captain Stevensons Point, Point Hicks, Glenaire and Armstrong Bay.



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Fig. 2—General coastal landform units



TABLE 1  
RADIOCARBON DATES FROM VICTORIAN COASTAL ARCHAEOLOGICAL AND GEOLOGICAL SITES

<i>Site name</i>	<i>Type of site</i>	<i>Material</i>	<i>Date B.P.</i>		<i>Reference</i>
ARCHAEOLOGICAL SITES					
Foreland					
Glenaire	rock shelter, base camp	charcoal	370± 45	NZ-367	Mulvaney 1962:5
Wilsons Promontory					
YW9A/5	A series, base camp	charcoal	3,060± 100	GaK-681	Coutts 1970:25
		charcoal	6,550± 100	GaK-683	Coutts 1970:25
YW11/1	A series, base camp	charcoal	3,920± 90	GaK-968	Coutts 1970:25
YW9A/6	A series, base camp	charcoal	3,480± 90	GaK-970	Coutts 1970:25
YW9A/2	B series, temporary camp				
		shell	2,840± 90	GaK6-80	Coutts 1970:25
		charcoal	1,260± 90	GaK-682	Coutts 1970:25
Tarwin	A series, ?	charcoal	6,010± 110	Gak-971	Coutts 1970:25
Pt. Hicks	B series, base camp	charcoal	1,425± 100	SUA-573	Coutts & Witter 1977:73
Clinton Rocks	B series, temporary camp				
		charcoal	220± 90	SUA-378	Coutts & Witter 1977:73
		charcoal	360± 90	SUA-377	Coutts & Witter 1977:73
Thunder Point	A series, temporary camp				
		charcoal	840± 98	SUA-674	Coutts 1978a:5
		charcoal	4,130± 200	SUA-675	Coutts 1978a:5
The Craigs	A series, temporary camp				
		charcoal	780± 95	SUA-775	Coutts 1978a:5
		charcoal	2,265± 100	SUA-774	Coutts 1978a:5
Goose Island	A series, temporary camp				
		charcoal	425± 95	SUA-776	Coutts 1978a:5
Goose Lagoon	A series, temporary camp				
		charcoal	1,177± 175	Libby	Gill 1955b:50
Armstrong Bay					
lower soil horizon	B series, base camp				
		shell	4,315± 195	GX-0059	Gill 1967:357
		charcoal	5,120± 120	GaK-610	Gill 1967:357
		shell	1,750± 115	GX-0060	Gill 1967:357
upper soil horizon	B series, base camp				
		charcoal	2,800± 100	Gak-611	Gill 1967: 357
		charcoal	538± 200	Libby	Gill 1955a
		charcoal	2,450± 100	SUA-673	Coutts 1978a:5
		charcoal	1,280± 80	GaK-1730	Campbell 1967
		charcoal	5,680± 120	GaK-1729	Campbell 1967
Pickering Point	A series, ?	shell	7,300± 150	GaK-2856	Gill 1972; 1973:135
Hinterland					
Cloggs Cave	temporary camp				
		charcoal	17,720± 840	ANU-1044	Flood 1974:177
		charcoal	8,720± 230	ANU-1001	Flood 1974:177
East Buchan	?	charcoal	2,760± 100	GaK-512	Anon. 1966:24
GEOLOGICAL SITES					
Bushfield	open site, eroding	bone	6,605± 190	GX-0151	Gill 1967:357
Merri Canal	open site	shell	6,500± 200	Ac-15	Gill 1967:357
Lake Pertobe	open site	shell	5,840± 320	Ac-14	Gill 1967:357
Moulden Quarry	open site				
		shell	3,750± 150	GX-0058	Gill 1967:357
		shell	6,570± 115	SUA-780	Gill (pers. comm.)
Dennington	open site				
		laminated mammillary calcite	8,700± 150	GaK-3920	Gill 1973:135

### 3. HEARTHES

These normally consist of a few waterworn pebbles or fragments of calcarenite arranged in the shape of a hearth. They may be associated with some charcoal and occasionally with small flaking floors. Such sites are quite common at Discovery Bay and Wilsons Promontory and have been found occasionally in other coastal areas.

### 4. WORKSHOPS

Typically these are locations where flint nodules were flaked. In some instances the stone fragments from these activities can be collected and the original cores pieced back together (Coutts 1978 b: plate 30). Such sites usually occur on very eroded sections of the coast and may be associated with other refuse from middens. The best examples of this type of site found so far are at Discovery Bay where large areas of the coast are peppered with flint flakes.

### CULTURAL VARIABILITY

The regional and chronological context of cultural variability is necessary for its understanding. However, there are still only a few well documented coastal sites in Victoria and discussion has been restricted to a comparison of base camps and temporary camps in eastern and western Victoria.

#### WESTERN VICTORIA

Temporary camps have been investigated in the foreland at Thunder Point and The Craigs, near Port Fairy and base camps excavated at Armstrong Bay, near Port Fairy, Seal Point and Glenaire near Cape Otway and Bridgewater near Portland.

#### Temporary camps

The sites at Thunder Point and The Craigs (Coutts 1977, Coutts & Witter 1977, Coutts *et al.* 1976) are typical temporary camps. They consist of heaps of shell mixed with charcoal, shallow hearth pits and hearth stones, the remains of crab and crayfish, a few stone flakes, fragments of ochre, and occasionally fragments of bone from land animals. Evidence from both these sites suggests that Aborigines came to the coast to collect shellfish, particularly *Subnirrella undulata*, from the rock platforms. The shellfish and occasionally some other animals were carried to the top of the dunes where they were eaten and the debris was thrown into heaps. This practice persisted from before 4 400 B.P. to at least 800 B.P.

TABLE 2  
PERCENTAGE INCIDENCE OF EACH TYPE OF SITE IN  
VARIOUS ENVIRONMENTS

Location of site	Percentage of each type of site in that locality							Total no. of sites
	M	SS	ST	FT	Q	AG	U	
Foreland:								
Dune systems	61	38			1		1	192
Beside swamps	61	33					6	18
Cliff top	64	33			1		3	97
Hillsides	67	33						9
Hinterland (excluding scarred trees):								
Coastal plain	41	27		4	4	19	5	70
Beside lakes/swamps	42	42				8	8	12
Upland/hillsides	61	15			8	8	8	13
Hinterland (including scarred trees):								
Coastal plain	12	8	70		1	6	1	230
Beside lakes/swamps	8	8	82			2	1	65
Upland/hillsides	22	6	64		3	3	2	36
M— middens and rock shelters SS— surface scatter                      Q— quarry ST— scarred tree                          AG— axe grinding FT— fish trap                              U— unspecified								

#### Base camps

Although the sites at Armstrong Bay (Tower Hill Beach) have never been extensively investigated, they appear to be base camps. No animal bones have been found *in situ*, but earlier researchers consider that many of those collected in the area derived from eroding midden deposits. These include the remains of whales, seals, fish and other marine animals, snake, Tasmanian devil, kangaroo, wombat, native cat, silvery-grey possum, ring-tail possum, bandicoot, rat, rufus-bellied wallaby, rat kangaroo, tiger cat and short-nosed bandicoot (Gill 1951, Mahony 1912). Human remains have also been found there. Although several radiocarbon dates ranging from  $538 \pm 200$  to  $5\ 680 \pm 120$  B.P. are available (Table 1), the provenance and associations of these dates are not always clear.



TABLE 3  
RELATIONSHIP BETWEEN DISTANCE OF SITES FROM ROCK  
PLATFORMS AND PERCENTAGE OF SITES ADJACENT TO  
SANDY BEACHES IN THE TAMBOON INLET—CAPE  
EVERARD STUDY AREA

Distance of sites from rock platform (km)	Percentage of sites situated adjacent to sandy beach environments	Per- centage of all sites
0 -0.5	38	58
0.6-1.0	0	0
1.1-1.5	4	4
1.6-2.0	21	13
2.1-2.5	7	4
2.6-3.0	7	4
3.1-3.5	4	2
3.6-4.0	0	0
4.1-4.5	7	4
4.6-5.0	0	9
Total number of sites	29	45

Recent preliminary studies of one of the middens (Coutts 1977) revealed a large occupation deposit, radiocarbon dated at  $2450 \pm 100$  B.P. associated with a rich assemblage of shellfish (predominantly *Subninja undulata*), animal bones (including those of snake, rat, wallaby, emu, bandicoot and bird) and stone tools (mostly made from coastal flint). There is also some evidence of bone tool manufacture.

Despite uncertainties about the origins of much of the surface material from these sites and about stratigraphy of the sites, it is evident that the area was visited by Aborigines for some thousands of

years. Bone and stone tools were manufactured there, and although collecting shellfish was the main activity, Aborigines appear to have hunted terrestrial animals further inland and brought them back to the coastal camps.

Midden deposits investigated by Lourandos (1976) at Seal Point near Cape Otway are similar to those at Armstrong Bay. Since they were more than 1 m deep, the implication is that Aborigines returned to the site periodically. Rich faunal remains indicate a varied diet, including shellfish, seal, small terrestrial animals and some fish. The site contained an assemblage of bi-points and evidence that the Aborigines made stone tools. The stone industry is apparently unsophisticated; that is, the tools have relatively little retouch. The most interesting feature of this site is a cluster of large circular depressions which Lourandos (1976: 188) believes may be the remains of sleeping pits. Although no radiocarbon dates are available for the site, the excavator considers it to be comparatively recent.

Three other sites excavated in western Victoria, situated in the hinterland but not far from the coast, are probably base camps. The first is a midden in a cave at Bridgewater about 1.5 km from the coast, near Portland (Lourandos 1976). The occupants collected shellfish, hunted medium to large land mammals and made a fairly sophisticated range of stone tools, including backed blades. Bone points do not appear to have been manufactured. Lourandos suggests that the differences between the assemblages at Seal Point and Bridgewater Caves are functional, and that the latter site is a temporary hunting camp. However, the differences could be a result of

TABLE 4  
RATIO OF MEAT VOLUME (ML) TO DEAD WEIGHT OF SHELL, FOR SELECT SPECIES OF MOLLUSCS COMMONLY FOUND IN  
ARCHAEOLOGICAL DEPOSITS

Environment	Species	Ratio of volume of meat (ml) to dead weight of shell (g)	Method of of harvesting	Energy input
Rock platform:				
	<i>Notohalotis ruber</i>	2.50	hand picked	high
	<i>Cellana tramoserica</i>	0.92	hand picked	high
	<i>Brachidontes rostratus</i>	0.83	scraped off rocks	low
	<i>Dicathais textilosa</i>	0.65	hand picked	high
	<i>Subninja undulata</i>	0.48	hand picked	high
	<i>Mytilus planulatus</i>	0.45	scraped off rocks	low
	<i>Cabestana spengleri</i>	0.35	scraped off rocks	high
	<i>Austrocochlea constricta</i>	0.34	scraped off rocks	high
Sandy beach:				
	<i>Plebidonax deltoides</i>	0.32	dredged	low
	<i>Anadara trapezia</i>	0.20	dredged	low

differences in age; the contents of the midden in the cave seem to be more those of a base camp.

The other two hinterland sites are 3 km from the coast at Glenaire, Cape Otway. Mulvaney (1962) has used data from these sites to synthesise the most recent period of Victorian prehistory. He obtained a date of  $370 \pm 45$  B.P. from one of them. His excavations revealed an extensive bone-working industry and a large number of stone artefacts made from a variety of rock types, although 90% of them were flint. Of 2 278 stone flakes excavated only four had been retouched, though many seem to have traces of use (Fullagar pers. comm.). The sites at Glenaire and Seal Point are comparable in this respect.

A notable feature of the Glenaire sites is the large quantity of rock platform shellfish. The rich variety of faunal materials from these sites indicates an economy based on shellfish and small land animals.

#### Discussion

Dates for these base camps have a long time span beginning more than 5 000 years ago. However, they share some features such as evidence for variable economies. They also have differences. For example middens in the Bridgewater cave and at Armstrong Bay contained backed blades, whereas middens at Seal Point and Glenaire did not. These differences may be chronological or functional, but backed blades seem to disappear from the Aboriginal tool kit in other parts of Australia during the early part of the first millennium B.P.

Bone tools are found at Armstrong Bay, Seal Point and Glenaire. They were manufactured at Armstrong Bay as early as 2 450 B.P. but there is not yet sufficient evidence to identify manufacturing techniques over a period of time; only two consistent types can be distinguished. The first, a uni-point tool usually 15-25 cm long, manufactured from a kangaroo fibula, has a spatulate to tapering point which is usually very worn. The other type is a bi-point, 5-7 cm long. Some of the bi-points are made from solid bone and have a blunt and a sharp end; others are symmetrical and made from light hollow bone.

There is no ready explanation for the large number or function of bone tools at these sites. The points may have been used to prize flesh from the shells of *Subnina undulata* (Mitchell 1958). A spatulate bone point in the National Museum carries a note by Mr Castwood, Port Fairy, 1849, suggesting that it was an 'Aboriginal chisel made

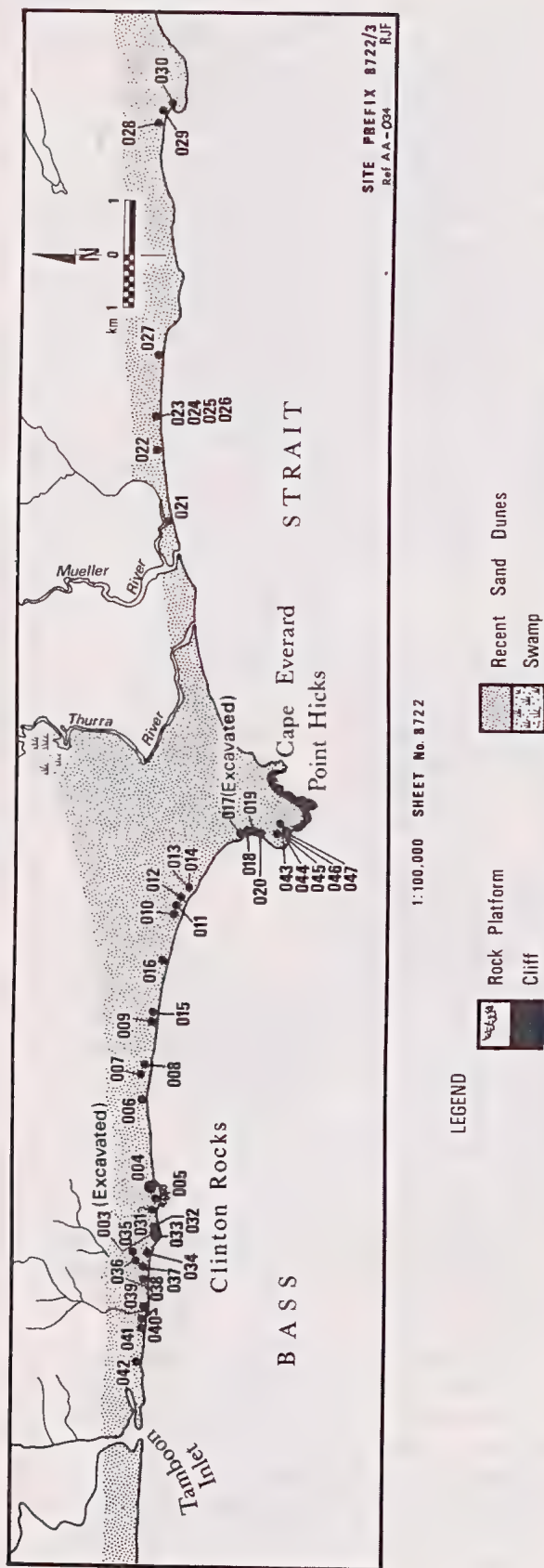


Fig. 3 — Tamboon Inlet — Cape Everard study area: distribution of archaeological sites



from the leg of a kangaroo, and used for cutting out the handle of the wooden shield'. However, the uni-points made from kangaroo fibula were probably generalised tools because they show a multitude of shapes and variable wear. Many have hinge snaps indicative of excessive stress. Bi-points were probably the tips of fishing spears, or gouges. Other functions for bone tools are listed in the ethnographic literature (e.g. Smyth 1878).

The bone implement assemblage at Glenaire is different to that at Armstrong Bay, lacking the spatulate uni-points made from kangaroo fibulae. It is dominated by bi-points, mainly the asymmetrical type, which are most similar to those described as points for fishing spears.

Faunal remains from the sites discussed above indicate that the Armstrong Bay and Clinton Rocks sites were occupied at least sometime during spring-summer. Evidence from other sites is not available or is inconclusive.

#### EASTERN VICTORIA

Temporary camps have been investigated in the foreland at Wilsons Promontory and Clinton Rocks and inland at Cloggs Cave and East Buchan. Base camps located in the foreland at Wilsons Promontory, Point Hicks and Captain Stevensons Point have been studied in detail.

##### *Temporary camps*

At Wilsons Promontory, field studies and excavations by the author have uncovered middens which are basically heaps of *Plebidonax deltoides* shells. One of these sites has been dated as  $1\,260 \pm 90$  B.P. (Coutts 1970: 25). Others have sparse scatters of flint and quartz flakes as well as the shells.

The site at Clinton Rocks is a concentrated deposit of marine shells showing no evidence of long breaks in occupation. At least nine shell layers are present. Layers 5 and 9 have been radiocarbon dated as  $220 \pm 90$  B.P. and  $360 \pm 90$  B.P. respectively (Coutts & Witter 1977), making this site broadly contemporaneous with those at Glenaire.

The dominant fauna at Clinton Rocks was the mussel *Brachidontes rostratus*, available from rock platforms nearby. The site also contained some fish, crabs, crayfish and terrestrial animals, including brush-tail possum and wallaby or kangaroo. It contained no evidence of workshop activity, though two pieces of burinated bone were recovered. The remarkable feature of this site is

the continuity in economic remains, a feature also noted at Thunder Point.

Two sites have been excavated in the hinterland, although they are not far from the coast. They are Cloggs Cave (Flood 1974) near Buchan, and a small rock shelter also near Buchan (Anon. 1966, Gallus pers. comm.). Few details are available for the latter. The data from the Cloggs Cave excavations suggest that it was a temporary camp throughout much of its 9 000 years of occupation.

##### *Base camps*

Two categories of base camp have been identified at Wilsons Promontory (Coutts 1970). 'A' series sites are associated with the last phase of stabilisation of the Pleistocene dunes. 'B' series sites are much younger. 'A' series sites typically contain lenses of shells embedded in a thick soil which caps the Pleistocene dunes. They date from about 6 500 B.P. and are associated with scatters of stone artefacts including hammerstones, anvils, cores, scrapers and a variety of flake and blade tools, such as backed blades, made from various materials (Table 5). There is very little bone in the deposits.

The second type of base camp—'B' series—also generally contains backed blades and other artefacts made of various materials (Table 5). However, the most recent sites do not contain backed blades and most of the tools in these sites are made from flint or quartz. Many of these sites contain the remains of small animals. Occasionally bone points are found. A distinct difference between the 'A' and 'B' series is the predominance of *Plebidonax deltoides*, a sandy beach species of shellfish, in the 'B' series sites. In contrast, the 'A' series middens are dominated by *Subnina undulata* and *Cellana* sp. from rock platforms.

The Point Hicks site contains several archaeological horizons and dates from 1 100 B.P. It is about 20 km from the Clinton Rocks site but, unlike the latter, is dominated by *Subnina undulata*. The remains of seal, dolphin and whale were found at the site. Analysis of the seal remains suggests that whole carcasses were dragged up to the site. Such mammals could have been a staple meat source, although there is evidence that the Aborigines fished and also hunted birds. No terrestrial animals are represented at the site.

Abundant stone flakes, some with secondary working, had been made from various materials (quartz, quartzite and chert). Artefacts include backed blades, hammerstones and numerous waterworn pebbles, some burnt. There is evidence

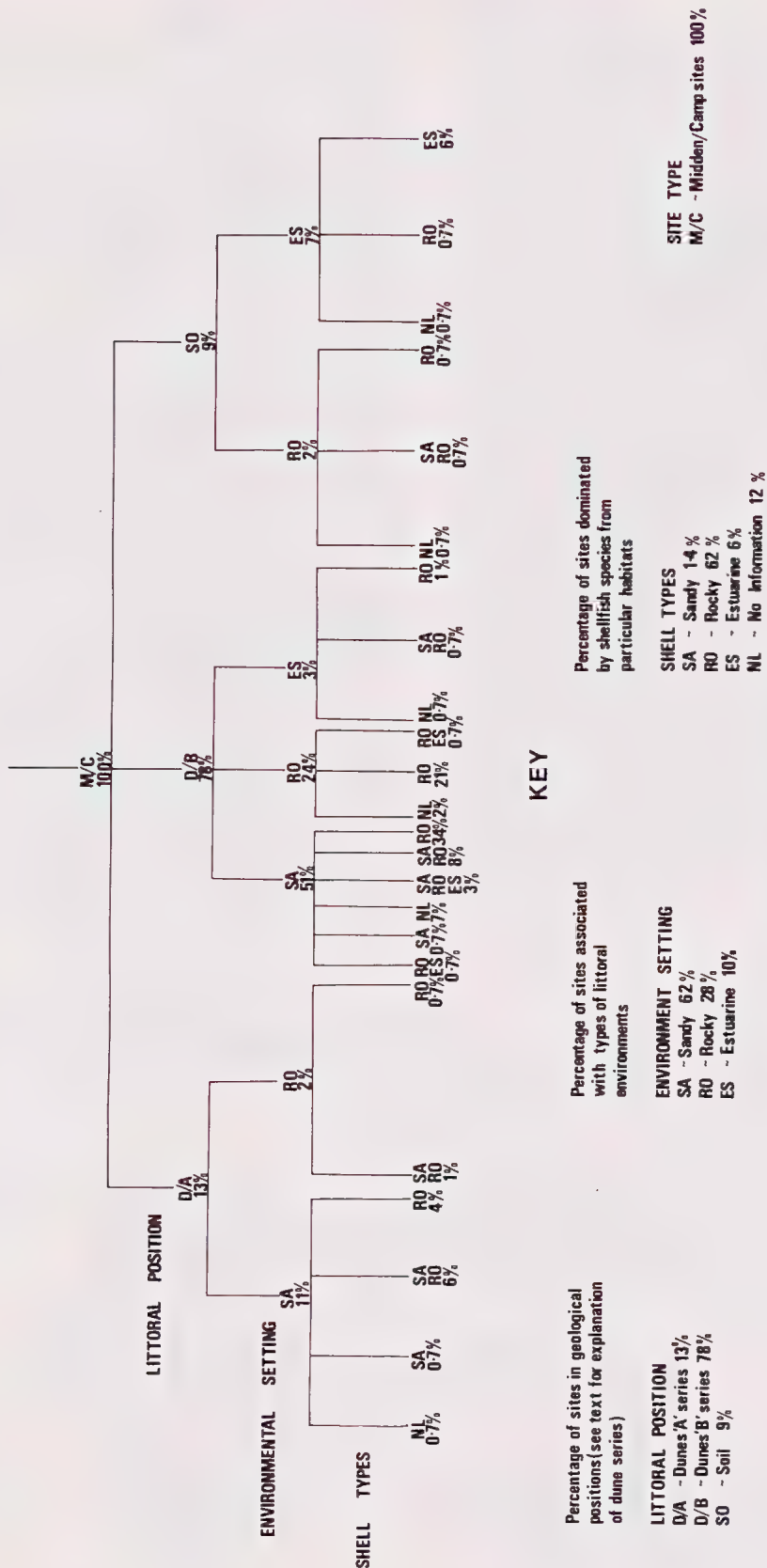


FIG. 4—Site classification of coastal middens: dendrogram



that bone points were made at the site. In summary, the Point Hicks site is similar to many of the earlier sites at Wilsons Promontory, except that the latter are not associated with animal remains or bone points.

Similar types of sites are found in many areas of the coast including Jack Smith Lake, Lake Denison and Marilyns Beach.

At Captain Stevensons Point, Mallacoota, there is an extensive midden on the cliff overlooking the inlet. Materials from excavations at this site are still being analysed, but preliminary assessments suggest that it is one of the richest coastal sites investigated in Victoria.

The inhabitants of the site exploited a wide range of habitats. From the inlet itself they collected shellfish (*Ostrea angasi* and *Anadara trapezia*) and caught fish (snapper or bream); from the rock platform areas, probably somewhere near Bastion Point, they collected shellfish (*Mytilus planulatus*, *Subnirrella undulata*, *Cellana* sp., *Dicathais textilosa* and *Cabestana spengleri*) and hunted seals; and in the surrounding woodlands they hunted terrestrial animals (such as wallaby and bandicoot). Stone tools have been found at this site (quartz is the most common material), though no readily recognisable tools or retouched specimens were found. Several large pointed and polished bone tools, some made from kangaroo fibulae, were recovered. The presence of several pieces of cut or damaged bone suggests that tools were made at the site.

This large site appears to have been occupied more or less continuously, although the Aborigines appear to have exploited different food resources at various times. Judged on its contents, the site belongs to the most recent period of Victorian prehistory.

Preliminary surveys in this area suggest that there are many similar sites around the margins of the inlet, reflecting the rich food resources of the area.

#### Discussion

These limited data are not vastly different to those described for western Victoria. Evidence of a change in materials and types of tools used over the centuries is a little stronger at the Wilsons Promontory sites. The latest sites do not contain backed blades, and the materials used in these sites are largely flint and quartz. Bone tools are found more frequently in these archaeological assemblages, though this might well be attributed to relatively favourable preservation conditions.

Once again economic variability is a feature and technological variability is also evident. For example, Aborigines at Marilyns Beach produced backed blades by notching a blade and then snapping it (Clark & Pickering 1978); Aborigines at Wilsons Promontory made backed blades by preforming blades on cores, striking them off and then retouching.

Faunal remains from Wilsons Promontory ('A' and 'B' sites) and Captain Stevensons Point in-

TABLE 5  
THE WILSONS PROMONTORY STUDY AREA: SUMMARY OF ARCHAEOLOGY

Type and environment of site	Material culture	Economy	Approx. age range
'A' series summit of old Pleistocene dunes	backed blades, hammerstones, anvils, fabricators, chalcedony, quartzite and chert; local material including flint and quartz; ochre	shellfish gathering almost exclusively from rocky shore platforms but also from bay environments	3,000-6,500 B.P.
'B' series northern end of isthmus	backed blades, edge-ground axes, unifacial tools, scrapers, hammerstones, chert, quartzite, quartz and flint	shellfish gathering predominantly from sandy beach	?
overlying 'A' series at southern end of beach and occurring in a number of areas at northern end of beach	few finished tools, but includes hammerstones, unifacial tools, edge-ground axes, scrapers. Materials predominantly flint and quartz	shellfish gathering from rock platform and sandy beach. Hunting of fish, birds and terrestrial mammals	1,000 B.P. down to and including the early contact period

dicating occupation at least some time during spring-summer.

## CONCLUSION

While some broad trends in the contents of midden sites can be discerned, the regional variation in the contents of coastal midden sites is considerable. What is needed now are more detailed studies of small areas of the Victorian coastline so that these variations can be identified. Areas of particular interest are structures (e.g. hearths, sleeping pits and house plans), variation in manufacturing technologies (which may reflect different ranges of activities, methods of manufacture and material usage), and variability in economic strategies such as methods of harvesting shellfish from different habitats or degrees of dependence on particular types of hunter-gathering.

Determining the seasonality of midden sites is another priority. Methods are being developed in Australia but more work is urgently required if site patterns are to be properly understood. Although a number of potential food resources available in the coastal region are seasonal, they are rarely found in archaeological deposits. Many of those that do occur are ambiguous seasonal indicators, often only of spring and summer periods.

Finally, because such a large proportion of Victorian coastal archaeological remains have already been destroyed, there is an urgent need for a research and site protection programme for those remaining. Unless this is done in the near future, potentially rich sources of information will be lost.

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## FISHERIES RESOURCES OF VICTORIA'S COASTAL AND OFFSHORE WATERS

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**ABSTRACT:** Information available from fisheries surveys and from records of commercial catches are used to describe, as far as possible, the distributions, movement patterns and abundances of species forming the demersal and pelagic fisheries resources of Victoria's coastal and offshore waters. A quantitative assessment of the total resource is precluded because most of the surveys have been unrelated and because many of the commercial fisheries are localised. Species which are only caught incidentally or are unexploited but have the potential of supporting a commercial fishery are also discussed.

Some of the region's physical characteristics, including the topography of the continental shelf and upper continental slope and the daily and seasonal water movement patterns which influence the fisheries resources, are briefly described.

### INTRODUCTION

During recent years reviews of the Victorian fishing industry (Burdon 1973), surveys of major fisheries in southeastern Australian waters (Anon. 1976a) and descriptions of the fish species present in Victorian waters (Anon. 1967) have been published, but in no publication has there been an attempt to collate the available information required to describe Victoria's ocean fisheries resources. After a century of commercial fisheries development, until recently unaided by research and sophisticated management, a review of such information is timely because the fishing industry, the community and the government are concerned about development prospects and management issues attendant on the proclamation of the 200-mile Australian Fishing Zone.

State and Commonwealth authorities have recently been re-examining data previously collected to serve local fisheries management and development purposes. The authorities' aims were to estimate the sustainable catch which each species could support, to determine the local fleet's catching capability and to decide how foreign interests might participate in exploiting these resources.

Strictly speaking, Victorian waters east of longitude 143° 40'E extend into Bass Strait only as far south as latitude 39° 12'S, that is 4 n mile south of Wilsons Promontory; the southern boundary

west of that longitude in 40°S. Fisheries resources which Victorian-based fishermen exploit north and south of the boundary are considered together below.

### TOPOGRAPHY OF THE SEABED OFF VICTORIA

#### BASS STRAIT

In Bass Strait oceanic swells, daily tidal currents and seasonal oceanic currents from the Great Australian Bight, Tasman Sea and sub-Antarctic waters have produced complex topographic and oceanographic conditions.

Bass Strait has a central basin 65-90 m deep with irregular bottom formations (undulations, scoured rocky areas and coarse sediment deposits) where currents are strongest, at its eastern and western entrances. Fine sand and mud also occur in the central basin.

Banks of fine sediment occur off the eastern Otway coast and from south of Phillip Island towards Wilsons Promontory. A sedimentary seafloor in shallow water occurs east and north-east of King Island.

In western Bass Strait, a depression caused by subsidence between fault lines (Keble 1946) and by fluvial erosion in the former Tamar Major river system (Dannevig 1915) extends from between King Island and Cape Otway in a north-easterly



direction towards Point Nepean, decreasing in depth from 100 m to 86 m, then along the Victorian coast to Phillip Island and south into the central basin. Numerous islands including the Curtis, Hogan and Kent Groups are situated between Wilsons Promontory and Flinders Island where current activity has produced a variety of bottom types including: rocky, bryozoan and sponge covered, gravel, shell and coarse sand. Areas of bryozoans and sponges, shells and coarse sands also occur east of the passage to the edge of the continental shelf.

#### CONTINENTAL SHELF OFF EASTERN VICTORIA

The continental shelf narrows from 100 n miles wide east of Wilsons Promontory to 10 n miles east of Cape Howe. In the oil and gas fields south-east of Lakes Entrance, there are restrictions placed on commercial fishing near drilling platforms, pipelines and wellheads.

Off far eastern Victoria, the deeper bottom (90-550 m) is covered with fine sediments and is even except for deep indentations or submarine canyons south of Marlo, Rame Head and Little Rame Head. The shallower bottom is predominantly coarse sand with areas of rocky outcrop.

#### CONTINENTAL SHELF OFF WESTERN VICTORIA

A prominent feature of the continental shelf off western Victoria is a rocky slope which starts in the west off Cape Duquesne, in water 60-90 m deep and becomes steeper and deeper to the south-east, converging towards the edge of the shelf south of Warrnambool. North of this slope, the bottom is largely rock or coarse sediment with extensive areas covered by bryozoans, shells and sponges. Sandy bottoms and seagrass beds occur in Portland Bay and Bridgewater Bay.

South of the rocky slope, the continental shelf is covered with fine sediments and narrows from 15 n miles south of Cape Nelson to 5 n miles south of Warrnambool. Much of the upper continental slope (220-770 m deep) from west of Robe to south of Warrnambool is covered with fine sand or mud and is trawlable. The continental slope is cut by steep canyons in a group south-west and south of Cape Bridgewater and irregularly between there and the Warrnambool area.

Upwellings off eastern and western Victoria (Rochford 1977a, 1977b) and the variable seasonal intrusions of three primary water masses (Newell 1961) must also influence the distribution, abundance and behaviour of fisheries resources off Vic-

toria but these influences are at best poorly understood.

#### SURVEYS OF FISH RESOURCES

The first important exploratory fishing program designed to assess the demersal fish and invertebrate resources of eastern Victoria and Bass Strait was conducted by the F.I.S. *Endeavour* between 1909 and 1914. The Commonwealth Government's commitment to the program is evident from the quality of the ship, of her company and of the scientists who subsequently described the biological material collected. A study of the distribution and abundance of marketable fishes and their ecological associations was in progress when the *Endeavour* was lost at sea in 1914. Since then no comparable program has been conducted in the region.

The results of the *Endeavour's* cruises still provide the most comprehensive descriptions of demersal and some pelagic species off Victoria. The outer part of the continental shelf and the upper continental slope between Gabo Island and Flinders Island were declared suitable for demersal trawling and the fish stocks were identified.

Subsequent trawling surveys in this area (Amos 1976a, Anon. 1977, 1979) and commercial trawling activity have qualified these earlier conclusions by identifying submarine canyons and foul ground, but proving conclusively the suitability of much of the bottom for demersal trawling.

Recent surveys (Anon. 1977, 1979, Gresik 1977) and resultant commercial trawling have also identified the extent of clear trawl ground and the demersal fish resources on the upper continental slope off western Victoria.

Early attempts to utilise pelagic species commercially provided some insight into their extent but most of the information on these resources results from detailed investigations of fish populations. An exception is Gould's squid *Nototodarus sloani gouldi* (McCoy); in this instance the first evidence that the species could support a substantial fishery off Victoria was the result of a feasibility study (Millington 1979).

#### COMMERCIAL FISHERIES DATA

Between 1914 and 1963, summaries of the monthly catch of each species landed at each port were the only records of the Victorian commercial catch. These summaries were used mainly to monitor the progress of the fisheries. During the 1950s, an estimate of fishing effort was used to provide more detailed information on changes in



the fisheries and in the abundance of the exploited segment of the resources.

Since July 1963, more details of catch and fishing effort have been collected from fishermen and have been used to monitor and manage the fisheries. During this period, a program of measuring samples of commercial catches of selected species has enabled the size and the sex composition of the total catches of these species to be estimated and monitored.

Thus a series of data which has become progressively more detailed has been collected and used to varying degrees by research and management workers. As a result, some characteristics of the exploited segment of several resources can be defined. The extent to which these fisheries data can be used to define the abundance of an exploited species throughout its range is limited by the distribution of the fishery in relation to that range, and by the uncertain relationships between catch rate and abundance for most species. An example is snoek *Leionura atun* (Euphrasen), a species which migrates long distances. Part of the snoek population in Bass Strait occurs seasonally in surface waters at varying distances off the central and western Victorian ports from which fishing is conducted by small, short-ranged boats. Because the main fishing method, trolling, depends on the response of the fish to the jig, fishing success varies with the distribution and abundance of food as well as that of the snoek itself. Consequently few inferences about the snoek population can be drawn from available data.

For species which are exploited through their entire range the fishery data can be extrapolated to allow an assessment of the total population. Although assessments of this kind are in progress, no quantitative estimate of a fishery resource in Victorian or nearby waters has been published.

Furthermore data for most species have not been summarised since 1974 so it is not possible to produce a chart showing distribution of recent commercial catches by statistical block or region.

Biological and population studies of fish exploited off Victoria have usually been localised relative to the overall distribution of the species. Such studies have been concerned mainly with those aspects which have a direct bearing on fisheries management of a species, for instance growth, movements, maturity and fecundity.

The assumptions and estimating procedures used for assessments, together with the types of fisheries data and population information available, have served the immediate management

purposes without a need for comprehensive ecological information. So, when a shark fisherman, a snapper angler or a penguin lover speculates on the ecological consequences of large-scale squid fishing, there may be sufficient facts known and safeguards taken to satisfy management authorities but these may not be tangible enough to dispel the fears of the questioner.

In the following sections, the results of biological and population studies and inferences from commercial fisheries statistics are used to describe the distributions, abundances, seasonal movements and some ecological determinants of exploited or potentially exploitable species off Victoria.

No attempt is made to describe the fisheries, the biology of the species or to quantify the fish resources from unpublished data. Also, because knowledge of the distributions of most species is so vague or fragmentary, no attempt has been made to map their distributions.

Many species which are commercially exploited by small inshore fisheries or are taken incidentally in larger inshore or offshore fisheries are not discussed in this paper because their numbers appear to be small or their development potential poor.

#### ABALONE

The species of abalone forming most of the Victorian catch is the blacklip abalone *Haliotis ruber* Leach which inhabits coastal reefs from the shore to depths of 30 m. These reefs are discontinuous from Discovery Bay to Warrnambool, Torquay to Wilson's Promontory (including Port Phillip) and Marlo to Cape Howe, but virtually continuous between Warrnambool and Torquay. Adult blacklip abalone occupy caves, crevices and steep rock faces exposed to water movements (Shepherd 1973). Juveniles occupy narrow crevices and the undersides of rocks and boulders.

This species is exploited over most of its range off Victoria; the total area of reef on which blacklip abalone are caught has been estimated as 6 000 ha (Anon. 1976a). Fishing intensity varies with degree of exposure of the reefs and with the distance of the reefs from fishing ports. Since the fishery was started almost two decades ago, fishing effort has fluctuated, but the species seems capable of supporting an annual catch of about 1 400 tonnes.

The other species exploited commercially is the greenlip abalone *Haliotis laevis* Donovan which also occurs on rocky bottoms from the shore to depths of 30 m, usually in areas of



moderate water movement (Shepherd 1973) along rocky channels or gutters and close to the interface between rock and sand or seagrass beds. In Victorian waters the species is relatively uncommon and is confined to coastal reefs west of Wilsons Promontory.

#### SCALLOPS

In 1966 exploratory dredging for coastal beds of commercial scallops *Pecten alba* Tate off Victoria revealed low concentrations of the old shells of dead scallops off Cape Otway, Port Phillip Heads, Cape Schanck and Waratah Bay (Sanders 1966). Small hauls of live scallops and large hauls of dead shells were dredged east of Wilsons Promontory and off Lakes Entrance.

Since 1970, surveys and commercial dredging have shown that concentrated beds of scallops occur on fine to coarse sandy substrates within 20 n miles of Lakes Entrance. The location of the beds change, and the overall abundance of scallops varies, but collectively these beds are the main source of the 1 500-4 400 tonnes landed annually at Lakes Entrance. Scallops on the more remote beds as far east as Point Hicks, off the Kingfish oil field (south-south-east of Lakes Entrance) and towards Wilsons Promontory, show greater fluctuations in abundance and are fished intermittently.

The transient nature of individual beds may be ascribed to the ocean currents which transport pelagic larvae. Occasionally, live scallops are taken in demersal trawls, on shark-fishing gear or are washed ashore in Discovery Bay, off the east coast of the Otway Peninsula, in Waratah and Venus Bays, off the east coast of Wilsons Promontory, or off Mallacoota.

Large concentrations of commercial scallops are also fished in Port Phillip.

#### CEPHALOPODS

Gould's squid is abundant in Victorian coastal and offshore waters although only since 1979, when feasibility fishing by Japanese boats started, have fisheries agencies obtained an estimate of the resource size. During autumn 1979, 10 boats took 1 641 tonnes of squid at rates of up to 12 tonnes per boat per night. Fishing operations were conducted from south-eastern South Australian waters to Wilsons Promontory, and catch rates were highest off central Victoria in waters 60-90 m deep.

Sightings and catches indicate that squid occur off Victoria throughout the year but are least abundant in coastal waters during winter (Winstanley 1979a). Several broods of squid probably occur at different times of the year in different localities; at least 5 broods of the sub-species *N. sloani sloani* Pfeffer occur off New Zealand (Kawakami 1976) and at least 3 broods of *N. sloani gouldi* are believed to occur in Tasmanian waters (Harrison 1979).

The southern calamary *Sepioteuthis australis* Quoy & Gaimard is a pelagic cephalopod of the bays, inlets and inshore coastal waters. Although the species is actively sought by fishermen in Victoria's bays, its occurrence in coastal waters is poorly recorded through incidental catches by trawlers.

One species of octopus (of uncertain identity) is caught incidentally in rock lobster pots and is known to occur on rock bottom in coastal waters. Other species of octopus and the cuttlefishes *Architeuthis braggi* (Verco) and *Amplisepia apama* (Gray) are caught in demersal trawl and Danish seine nets on sand, gravel and stony substrates off eastern and central Victoria mainly during autumn and spring.

#### PRAWNS

Two penaeid species are exploited in eastern Victorian inlets and estuarine lakes; the eastern king prawn *Penaeus plebejus* Hess and the school prawn *Metapenaeus macleayi* (Haswell). Both species are also taken by small trawlers in coastal waters 2 to 40 m deep adjacent to Lakes Entrance. The numbers in which these species move out of the Gippsland Lakes as advanced juveniles and adults vary from year to year, for instance the commercial trawl catch was 14 tonnes in 1977 but less than one tonne in 1978. This movement into coastal waters usually occurs during January to May.

Eastern king prawns occur regularly in Corner Inlet and adjacent coastal waters, small numbers are trawled seasonally off San Remo, and some have been obtained from Western Port and Port Phillip but there is no evidence that large numbers occur regularly west of Wilsons Promontory.

Specimens of the royal red prawn *Hymenopenaeus sibogae* (de Man) have been trawled and identified in the stomach contents of fishes from the continental slope off eastern (Anon. 1977 a, Gorman & Graham 1978) and western Victoria. If they are as abundant there as they are off New South Wales they could form the basis of a future fishery.



## ROCK LOBSTER

The southern rock lobster *Jasus novaehollandiae* (Holthius) inhabits rocky ground on the continental shelf off Victoria. The reefs in these waters vary from granite off Wilsons Promontory, to aeolianite and basalt in Portland Bay and bryozoa and sponge-covered limestone in deeper waters off eastern and western Victoria.

The abundance of rock lobsters and the area of rocky ground decrease from west to east along Victoria's coast. Off western Victoria, the bottom of the offshore incline, described previously, is the seaward boundary of the commercial fishing grounds (Winstanley 1980). Small numbers of rock lobsters occur on low limestone outcrops beyond this incline at depths of 146 to 165 m. South-west of Cape Otway, several reefs rise from 60 to 80 m to 25 to 35 m. Between Cape Otway and Wilsons Promontory and around the Bass Strait islands, the rock lobsters are largely confined to coastal reefs. Off eastern Victoria, reefs suitable for rock lobsters are sparse; patches of reefs occur 3 to 5 n miles offshore from the Ninety Mile Beach to Marlo, along the coast from Marlo to Cape Howe and offshore to depths of 110 m, east of Lakes Entrance.

After more than a century of commercial fishing which has become intensive since 1960 throughout most of its range, the rock lobsters off Victoria appear capable of supporting an annual catch of about 600 tonnes including 400 tonnes from west of Cape Otway.

Recent tagging studies have not shown systematic movement patterns off western Victoria but there is evidence of south-westerly movement along the eastern Otway coast towards and beyond Cape Otway.

## SOUTHERN BAY LOBSTER

Scyllarid species occur throughout the full range of depths fished by Victorian fishermen (0 to 650 m) but only one, the southern bay lobster or Balmain bug *Ibacus incisus* (Peron), is exploited commercially.

Catches from experimental beam trawling east of Wilsons Promontory and off central Victoria (Winstanley 1977) indicated that southern bay lobsters are most abundant in water of 30 to 80 m deep; more intensive otter trawling east of Cape Woolamai (Winstanley 1979a) showed that they are most abundant on clean sandy substrates in 30 to 50 m. Commercial trawling for southern bay lobsters is most intensive in the coastal waters be-

tween Lakes Entrance and Marlo on sand and gravel substrates at depths of 2 to 40 m.

## CRABS

One species of crab, the giant crab *Pseudocarcinus gigas* (Lamarck), occurs on the continental shelf and upper continental slope off western and eastern Victoria at depths of 18-420 m. Commercial fishermen catch giant crabs in rock lobster pots set mainly at the fringes of rocky bottom and on low profile reefs at depths of 54 to 126 m off western Victoria (Winstanley 1979b).

Giant crabs are more abundant and tend to be larger (up to 10 kg) at the edge of rocky bottom; smaller giant crabs of 4 to 6 kg are more sparsely distributed on low profile reefs and on sponge and bryozoan-covered bottoms (Winstanley 1979d).

The other main commercially exploited species is the swimming crab *Ovalipes bipustulatus* (Milne-Edwards). Although swimming crabs are widely distributed on shallow sandy bottoms they are caught regularly only by small trawlers which operate in the coastal waters between Lakes Entrance and Marlo.

Another species, the great spider crab *Leptomithrax australiensis* (Miers), is frequently caught in trawls and dredges and entangled in shark gillnets. This species occurs from the shore to depths of at least 814 m off South Australia (Hale 1927) and is widely distributed and at times locally abundant on the continental shelf off Victoria. During autumn to spring divers have seen thousands of these crabs congregating at depths of 2-25 m in bay and coastal waters. Great spider crabs may be regarded as a resource with the potential for development as a commercial fishery.

## EDIBLE SHARKS

Gummy sharks *Mustelus antarcticus* Gunther and school sharks *Galeorhinus australis* (Macleay) occur on the continental shelf and upper continental slope. The former species is most abundant in coastal waters, particularly in eastern Bass Strait, where it feeds largely on benthic invertebrates, and is caught on low profile reefs, and sponge and bryozoan-covered substrates.

School sharks inhabit a similar depth range but are more abundant than gummy sharks in offshore waters. During winter, adult school sharks migrate to deeper waters off Victoria and Tasmania and into South Australian and New South Wales waters. During spring, they move back onto the continental shelf off Victoria and Tasmania. Pregnant females move into the bays



and estuaries to release their young which spend about 3 years in these sheltered waters (Anon. 1976a).

Both gummy and school sharks are effectively exploited over most of their range and Victorian annual landings average about 1 500 tonnes.

Southern saw shark *Pristiophorus nudipinnus* (Gunther), angel sharks (Squatinae) and elephant shark *Callorhynchus milii* Bory de St Vincent are an incidental but important part of the marketed catch of the shark gillnet and the trawl fisheries on the continental shelf. The common saw shark *P. cirratus* (Latham) is caught and marketed by trawlers working on the continental slope at depths down to 440 m mainly during winter; various dogfishes (Squalidae) also form part of the catch on the slope.

#### PILCHARDS, ANCHOVIES AND SPRATS

Pilchards *Sardinops neopilchardus* (Steindachner) and anchovies *Engraulis australis antipodum* Gunther are the most exploited of the clupeiform fishes in Victorian waters. Sandy sprats *Hyperlophus vittatus* (Castelnau) and blue sprats *Spratelloides robustus* Ogilby are caught with pilchards and anchovies in Victorian bays, estuaries and coastal waters. The occurrence of four species is known mainly from commercial fishing in Port Phillip and off Lakes Entrance.

Off western and central Victoria, adult pilchards occur in coastal waters during autumn and winter; off eastern Victoria they occur in coastal waters throughout the year.

Adult anchovies three years of age and older leave the bays, inlets and estuaries (except Port Phillip) and are most abundant in inshore waters between April and October each year (Blackburn & Tubb 1950). In summer they return to the protected waters to spawn. From May to October in some years, large schools of anchovies have been seen in western Victorian coastal waters.

During autumn and winter, large schools of anchovies and pilchards occur in the surface waters close to shore off eastern Victoria where they are taken in purse seines in calm seas.

#### LANTERN FISH AND LIGHTFISH

Exploratory midwater trawling has shown that lantern fish and lightfish, notably *Lampanyctodes hectoris* (Gunther) and *Maurolicus muelleri* (Gmelin), form an abundant unexploited pelagic resource at the edge of the continental shelf and the continental slope. *Lampanyctodes hectoris* has been trawled in eastern Bass Strait in May, June,

July, November and December (Anon. 1976b, 1976c, 1977c) and at the edge of the continental shelf south and east of Portland during winter (Anon. 1976c). Specimens have been identified in the stomach contents of fish caught on the continental slope south of Port Fairy in November (Winstanley 1978). *Maurolicus muelleri* has been trawled in offshore eastern Bass Strait waters in March, November and December (Anon. 1977b, 1977c).

#### COD

Southern rock cod *Pseudophycis barbatus* (Gunther) occurs on rocky bottoms, on low profile reefs and on sandy bottoms among sponges and bryozoans from the shore to depths of at least 128 m. Commercial fishing for this species has been most productive in coastal waters from Lakes Entrance to Portland between late autumn and early spring, but the species now appears to be less abundant and is taken mainly as an incidental part of the trawl and Danish seine catch. Red cod *P. bachus* (Bloch & Schneider) also occurs in commercial catches but is not distinguished from southern rock cod in the catch figures.

Ribaldo or deepsea cod *Mora dannevigii* Whitley occurs on the continental slope off eastern and western Victoria at depths of 180 to 1 100 m (Winstanley 1979c) and is caught incidentally in demersal line and trawl fisheries. The frequent occurrence of dark parasitic infestations in the flesh impairs the market value of this fish.

#### LING

At least two species of ling are exploited commercially in Victorian ocean waters: rockling *Genypterus blacodes* (Bloch & Schneider) and banded ling *G. microstomus* Regan.

Rockling inhabit reefs from the shore to depths of at least 130 m and is probably the species caught on lines and in trawls at depths of 280 to 650 m on the continental slope off eastern and western Victoria.

Banded ling occur on sand, sponge and bryozoan-covered substrates in coastal waters where they are taken in trawls.

Australian tusk *Dannevigia tusca* Whitley is trawled on the continental slope off western Victoria but unlike the previous two species, tusks are not highly regarded by consumers.

#### BLUE GRENADIER

Blue grenadier or New Zealand whiptail, *Macruronus novaezelandiae* (Hector), occurs on



the continental shelf and slope to depths of at least 730 m. Recently large catches have been taken off eastern Victoria by trawlers operating from New South Wales and catches from adjacent waters off Tasmania, South Australia and New South Wales indicate that blue grenadier are particularly abundant at depths of 366 to 800 m.

Off western Victoria, exploratory trawling (Anon. 1979, Gresik 1977) showed that blue grenadier occur mainly at depths of 290 to 550 m during autumn and winter. Recently, commercial catches have been highest at depths of 550 to 586 m from late summer to winter. Small individual fish have been caught at depths of about 10 m in Portland Bay during summer. Off eastern Victoria exploratory trawling (Anon. 1977, 1979) showed that blue grenadier occur at depths of 117 to 550 m and are most abundant at depths of 360 to 550 m during summer and autumn.

#### NANNYGAI

Nannygai or redfish *Centroberyx affinis* (Günther) occur mainly on the continental shelf off Victoria. Nannygai are an incidental part of the demersal trawl catch at depths of 110 to 220 m off eastern Victoria and 27 to 82 m off central Victoria (mainly in autumn).

#### DORIES

Three species of dories are abundant and exploited by demersal trawling in deeper waters of the continental shelf and continental slope off eastern and western Victoria: the silver dory *Cyttus australis* (Richardson), the mirror dory *Zenopsis nebulosis* (Temminck & Schlegel) and the king dory *Cyttus traversi* Hutton. Silver dories occur in coastal water and are incidental in demersal catches but they are prominent at depths of 110 to 220 m off eastern Victoria in spring and summer and at 512 to 586 m off western Victoria for many months of the year.

During summer and autumn, mirror dories are most abundant and are trawled at depths of 110 to 512 m off eastern Victoria and 200 to 428 m off western Victoria.

The king dory is most abundant and is trawled during summer and autumn at depths of 120 to 265 m (they occur as deep as 550 m) off eastern Victoria and at depths of 220 to 586 m off western Victoria.

The John dory *Zeus faber* Linnaeus occurs from the coast to depths of at least 137 m and is largely incidental in demersal catches off eastern and central Victoria.

#### GURNARD PERCHES

One species, the ocean perch *Helicolenus papillosus* (Bloch & Schneider), is widely distributed, abundant and commercially exploited mainly by demersal trawlers.

This species, also known as coral perch, big-eye gurnard or red gurnard perch, occurs from the shore to depths of 640 m and is caught, at least in small numbers, wherever and whenever trawlers operate off Victoria.

Off eastern Victoria, ocean perch are most abundant at depths of 348 to 480 m during autumn. Off central Victoria, they are trawled in coastal waters at depths of 30 to 82 m in all months. Off western Victoria, they are regularly trawled at depths of 165 to 586 m and are particularly abundant at depths of 293 to 311 m in winter. Other gurnard perches, such as the thetis fish *Neosebastes thetidis* (Waite), are caught incidentally off Victoria but they are not identified in catch records.

#### GURNARDS

Two species of gurnard are exploited on the continental shelf; red gurnard *Chelidonichthys kumu* (Lesson & Garnot) and latchet or sharp-beaked gurnard *Pterygotrigla polyommata* (Richardson). Both are demersal, widely distributed and caught throughout the year, but large catches are seasonal.

Red gurnard occur from the shore to depths of at least 220 m and are most abundant in spring at depths of 110 to 220 m off eastern Victoria and at 20 to 90 m off central Victoria.

Latchet occur from the shore to depths of at least 550 m and are abundant at depths of 140 to 165 m in autumn off eastern Victoria, 54 to 82 m in autumn and spring off central Victoria and 124 to 132 m in autumn and winter off western Victoria.

The spiny or cocky gurnard *Paratrigla papilio* (Cuvier & Valenciennes) is abundant in coastal waters 36 to 82 m deep off central Victoria but is not commercially exploited because of its small size. Another unexploited species, the painted or spotted gurnard *Pterygotrigla picta* Günther, is common at depths of 152 to 403 m off eastern Victoria.

#### FLATHEADS

The most commercially important species of flathead in Victorian waters, the tiger flathead, *Neoplatycephalus richardsoni* (Castelnau), predominates in the flathead caught by trawl and



Danish seine boats based at Lakes Entrance. Tiger flathead occur on sandy bottoms from the shore to depths of at least 300 m and are caught throughout the year. During summer, large schools form in water 55 to 128 m deep and during winter and spring these flathead are more widely dispersed and are most abundant in water 110 to 220 m deep.

West of Lakes Entrance, tiger flathead are less abundant and the very similar species, the toothy flathead *N. speculator* Klunzinger, is more numerous. Toothy flathead predominate in commercial catches of flatheads from continental shelf and upper continental slope (to depths of 270 m) west of Wilsons Promontory. Off central Victoria toothy flathead are most abundant during summer and autumn and are trawled at depths of 30 to 70 m.

The deepwater flathead *N. conatus* Waite & McCulloch is a small component of the demersal trawl catch taken on the continental slope off western Victoria, where it is caught in waters 250 to 310 m deep.

Sand flathead *Platycephalus bassensis* Cuvier & Valenciennes is common on shallow sandy bottoms in coastal (and bay) waters from the shore to depths of 80 m. Catch rates for this species are highest during summer. The demand for sand flathead is not as high as that for the three species of *Neoplatycephalus* and sand flathead are generally marketed as an incidental part of the catch in the trawl and Danish seine fisheries. Sand flathead form less than 5% of the flathead catch off Lakes Entrance and about 30% of the flathead catch off central Victoria.

Long-nosed flathead, *P. caeruleopunctatus* (McCulloch), is a minor component of the flathead resources of coastal waters.

#### WHITINGS

School whiting *Sillago bassensis* Cuvier & Valenciennes occurs mainly on clean sandy bottom from the shore to depths of 80 m. The annual Victorian catch of about 600 tonnes is caught almost entirely by the Lakes Entrance Danish seine fleet which fishes the abundant and extensive school whiting on the broad sandy continental shelf at depths of 18 to 55 m.

Commercial and experimental trawling east of Wilsons Promontory (Amos 1976a, Winstanley 1977) and off central Victoria (Winstanley 1977, 1979a) have shown that commercially exploitable concentrations of school whiting occur from the shore to depths of 55 m. Off western Victoria the

species occurs where there is suitable shallow sandy bottom, for instance in Portland Bay.

Catch rates for school whiting are highest between autumn and spring (Winstanley 1979a). Amos (1976a) reported that catches are higher at night and at the time of the new moon.

King George whiting, *Sillaginodes punctatus* (Cuvier & Valenciennes), is largely exploited in the bays and inlets, but there is some commercial and amateur fishing on seagrass beds and on sandy patches among the shallow reefs off central and western Victoria. At times large whiting are taken in trawls or Danish seines on rough bottom at depths of 45 to 55 m off central Victoria.

Sand whiting *Sillago ciliata* Cuvier & Valenciennes are common in coastal waters but are not exploited commercially.

#### YELLOWTAIL KINGFISH

The yellowtail kingfish, *Seriola grandis* Castelnau, is a pelagic species which forms large schools in bays, inlets and on the continental shelf. Kingfish are caught off eastern Victoria from the shore to depths of 128 m from summer to winter; in bays, estuaries and inlets from spring to autumn; and in central and western Victorian coastal waters in late spring and summer.

#### SILVER TREVALLY

Young silver trevally, *Caranx georgianus* (Cuvier & Valenciennes), are common in inlets and estuaries; older fish are caught in coastal waters as deep as 110 m. Commercial catches from open waters are small and usually incidental in gillnets or trawl nets.

#### MACKERELS

Jack mackerel, *Trachurus declivis* Jenyns, occurs in all Victorian open waters during at least part of the year. Although their abundance is not known, jack mackerel stocks are regarded as being one of the outstanding unutilised resources of south-eastern Australian waters (Anon. 1978). They are least abundant during winter, when the main concentrations are off far-eastern Victoria (e.g. Anon. 1977c), and are most abundant in eastern Bass Strait, particularly during summer and autumn when large schools occur in surface and subsurface waters. Exploratory midwater trawling (e.g. Anon. 1976b, 1978b; Gorman & Graham 1974, 1976) has shown that schools occur mainly in mid and bottom waters during spring and early summer. Exploratory demersal trawling (Gresik 1977), pelagic trawling (Anon. 1976c) and



incidental commercial catches have shown that jack mackerel occur off western Victoria mainly during autumn and winter.

They are not actively sought by Victorian fishermen, and commercial catches are taken incidentally by demersal trawlers whose catches show that at least some mackerel occur close to the bottom during most months of the year with the largest catches taken at depths of 128 to 200 m in winter and spring. Incidental catches in demersal trawls and the infrequency of surface sightings indicate that off central Victoria jack mackerel are most abundant in late autumn and spring, when they occur mainly in mid and bottom waters.

Yellowtail, *T. mccullochi* Nichols, and common or slimy mackerel, *Scomber australasicus* Cuvier & Valenciennes, also occur seasonally in coastal waters but are not actively exploited.

#### AUSTRALIAN SALMON

Two subspecies of Australian salmon, the eastern *Arripis trutta marginata* (Cuvier & Valenciennes) and the western *A. trutta esper* (Whitley), occur, mainly as schools of juveniles and young adults aged 0+ to 5+ years, in the bays, inlets and inshore open waters of Victoria (Stanley 1978). Younger fish of both subspecies school together in the protected bays and inlets, and older fish occur in the inshore waters.

Analysis of commercial catches shows that fish aged 1+ to 4+ years from the eastern subspecies are common in central Victorian waters and predominate off eastern Victoria; fish aged 1+ to 3+ years from the western subspecies are common as far east as the Gippsland Lakes and predominate off western Victoria. Although these young salmon are the basis of an annual 200 to 700 tonne Victorian fishery, the two subspecies are unusual in that, as they mature, they eventually separate and migrate into coastal waters of New South Wales and South and Western Australia where the adult fish reproduce and are exploited to a far greater extent.

#### SNAPPER

At least two stocks of snapper *Chrysophrys auratus* (Bloch & Schneider) occur in Victorian waters: the eastern stock which ranges between far eastern Victorian and northern New South Wales waters, and the western stock which ranges from Western Port to south-eastern South Australian waters (Sanders 1974). The status of snapper between these two regions, that is, from Wilsons Promontory to Mallacoota is not known.

Although snapper are occasionally taken in trawls on smooth bottom, between the shore and the edge of the continental shelf, they are most abundant on low profile reefs and on the fringes of rocky reefs. Juveniles occur in the bays, inlets, estuaries and coastal waters.

Each spring part of the western stock moves from the west along the coast and into Port Phillip and Western Port and returns to the west during the late autumn. Despite the regularity of this seasonal movement there is evidence that the whole stock does not migrate. For instance, snapper occur at the eastern and western extremities of the range during summer and in Port Phillip throughout the year.

The eastern stock is found off far eastern Victoria during the summer and autumn and off New South Wales during the rest of the year.

Snapper occur among coastal reefs off Corner Inlet and the Ninety Mile Beach during spring and summer and on similar reefs off Lakes Entrance during summer and autumn.

#### RED MULLET

The red mullet, *Upeneichthys porosus* (Cuvier & Valenciennes), occurs on sand, sponge and bryozoan-covered bottoms, on seagrass beds and at the edges of shallow reefs in coastal waters and bays. The annual commercial catch is low and is taken mainly by trawlers and Danish seiners; catch rates are highest during summer and autumn (Winstanley 1979a) at depths of 30 to 70 m. During autumn east of Wilsons Promontory, red mullet are most abundant in water of 20 to 50 m deep (Winstanley 1977).

#### MORWONGS

Tarakihi or jackass fish, *Nemadactylus macropterus* (Bloch & Schneider), is an important component of the offshore trawlfish resource off Victoria. This species occurs on sand, reef, sponge and bryozoan-covered substrates at all depths from the shore to 476 m (Anon. 1979). Juveniles as small as 10 cm caudal fork length occur in shallow waters (40 to 70 m) off central Victoria.

Commercial catches indicate that between late autumn and spring, tarakihi are most abundant at depths of 110 to 220 m off eastern Victoria (from Gabo Island to the Kingfish B oil platform) and at depths of 165 to 293 m off western Victoria. At other times of the year, smaller commercial catches are taken at depths of 110 to 146 m off eastern Victoria.



Off central Victoria, tarakihi are trawled at depths of 36 to 80 m and are most abundant during autumn (Winstanley 1979a).

Blue morwong *Nemadactylus valenciennesi* (Whitley) is caught incidentally in shark gillnets and in trawls on the continental shelf.

#### SNOEK

Snoek or barracouta are common in bays and coastal and offshore waters of southern Australia. Blackburn and Gartner (1954) described five south-east Australian populations of which three migrate to and from Victorian and adjacent waters at different times of the year to spawn: one population migrates from eastern Bass Strait to eastern Victoria and southern New South Wales waters during winter and spring; another population migrates from the eastern Great Australian Bight into western Victorian waters during autumn and winter; and the Bass Strait population which is most exploited, moves west to South Australian waters during spring and summer and returns during autumn.

Snoek school and feed in surface waters mainly during their spawning migrations and occur lower in the water column at other times of the year. Although they are only lightly exploited and are abundant in Victorian and adjacent waters, their accessibility to traditional trolling boats is believed to vary considerably with the distribution of their main foods—euphausiids and anchovies (Blackburn 1957). Victorian catches have therefore varied between 87 and 2 521 tonnes during the period 1970/71 to 1977/78. Demersal trawling catches (e.g. Winstanley 1979a) confirm that snoek may be abundant in coastal waters when trolling and the absence of surface schools suggest otherwise.

Although details of the distribution of snoek populations off Victoria are not known, they are caught from the shore to depths of at least 220 m. During late winter and spring they are trawled in waters 110 to 220 m deep off eastern Victoria and 110 to 128 m deep off western Victoria.

#### GEMFISH

Gemfish, *Rexea solandri* (Cuvier & Valenciennes), is a migratory school fish which is caught in demersal trawls at depths of 110 to 600 m over the upper part of the continental slope off eastern and western Victoria.

Off eastern Victoria, gemfish are caught mainly during spring in water 146 to 220 m deep and during summer in water 110 to 146 m deep. Off

western Victoria, gemfish are caught mainly during summer and autumn in water 275 to 567 m deep; small quantities are taken at other times in water 330 to 550 m deep. During winter, catches off Victoria are small in contrast with those taken from the large northbound spawning schools exploited in water 270 to 540 m deep off New South Wales.

#### FROSTFISH

Southern frostfish, *Lepidopus lex* Phillipps, occurs on the continental slope. Occasionally they are trawled in commercial quantities (e.g. Gresik 1977), particularly during summer and autumn, but they are not exploited regularly off Victoria.

#### TUNAS

Serventy (1941) reported the occurrence of five species of tuna in Victorian waters: southern bluefin tuna *Thunnus maccoyii* Castlenau, albacore *Thunnus alalunga* (Bonnaterre), yellowfin tuna *Thunnus albacares*, skipjack or striped tuna *Katsuwonus pelamis* (Linnaeus), and bonito *Sarda australis* (Macleay).

Southern bluefin tuna occur off far eastern Victoria from mid-winter until the end of summer and off eastern and central Victoria between November and May (Serventy 1941). Most years they are observed during autumn and small numbers are trolled off the Otway coast and western Victoria.

Albacore occur off eastern Victoria, eastern Bass Strait and, occasionally, off central Victoria during summer (Serventy 1941). Unlike the other tunas they are usually caught singly (Anon. 1954).

Yellowfin tuna also occur off far eastern Victoria during summer (Serventy 1941).

During summer and autumn, striped tuna are abundant off eastern Victoria (Serventy 1941) and, at least in some years, off Portland.

Bonito also occur off eastern and central Victoria during summer and autumn; they are occasionally caught as far west as Port Fairy (Serventy 1941).

#### TREVALLAS

The two species of trevalla exploited commercially are blue-eye or deepsea trevalla *Hyperoglyphe antarctica* (Carmichael) and warehou, snotgall trevalla or sea bream *Seriotelella brama* (Gunther) which is also referred to as "haddock" by Portland fishermen and anglers.



Deepsea trevalla are benthopelagic fish feeding mainly on macroplankton over the continental slope of eastern and western Victoria. Exploratory droplining (Winstanley 1979c) showed that they occur in water 180 to 770 m deep, and that catch rates are greatly influenced by seasonal schooling, dispersion and movement patterns. This exploratory fishing and subsequent commercial line, gillnet and trawl fishing have shown that trevalla are most abundant in water 350 to 500 m deep from winter to summer.

Commercial fishermen often misidentify warehou as deepsea trevalla although the former is readily distinguishable by its blotchy coloration and smaller mouth. Schools of juvenile warehou are often observed by divers and warehou are often taken in trawls in shallow coastal waters. Adult warehou usually occur over reefs in coastal waters and over low profile reefs and sandy bottoms on the continental shelf to depths of 220 m. The largest commercial catches are taken in gillnets and, occasionally, trawls at depths of 110 to 220 m off eastern Victoria. Small quantities are trawled off central Victoria during most months and occasional large catches have been trawled at 110 to 128 m off western Victoria.

Mackerel trevalla *S. maculata* (Forster) also occurs offshore from eastern and western Victoria (Gresik 1977) but its distribution, abundance and degree of exploitation are uncertain because fishermen confuse this species with warehou.

#### FLOUNDERS

The species forming most of the flounder catch from Victorian coastal waters is the longsnouted flounder *Ammotretis rostratus* Gunther, which fishermen commonly referred to as "sole"; the remainder of the catch consists of greenback flounder *Rhombosolea tapirina* Gunther and spotted flounder *Ammotretis tudori* McCulloch.

The annual commercial catch of flounders from coastal waters is small and mostly incidental in the catches in the Danish seine, trawl and gillnet fisheries off eastern and central Victoria. Catch rates off eastern Victoria show no clear seasonal pattern but those off central Victoria are consistently highest during winter and spring (Winstanley 1979a).

#### SPECIATION OF EXPLOITED STOCKS

Although in this paper speciation of fishes is not discussed, it is appropriate to mention briefly the role which the periodic barrier across Bass Strait must have played in the speciation of exploited

species such as Australian salmon, snoek, snapper and the flatheads. The end of the range of each of these exploited species is somewhere in Bass Strait. As well as having distinct migration patterns some populations of pelagic species to the east and west of Bass Strait have differences in anatomy, feeding and growth. Examples include the growth rates of snapper stocks (Sanders & Powell 1979) and the anatomy of the Australian salmon subspecies (Malcolm 1961). The ancestral stocks of these species have evidently been divided by the Bass Strait barrier and speciation has occurred as a result of the differing physical and biotic environments off southern and eastern Australia.

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## POSITION FIXING FOR MARINE AREAS OF VICTORIA— MULTIDISCIPLINARY UTILISATION

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### INTRODUCTION

Many users of the seas require accurate position fixing facilities. This paper examines the survey requirements of a large scientific marine study, in particular the position fixing methods and equipment. The depth of discussion is such that the material can be of general use to both surveyor and scientist.

In North America, Europe, South Africa, New Zealand and elsewhere, continental shelves have received considerable scientific attention in keeping with their increasing utilisation and with growing awareness of their potential. Despite the vast area of the continental shelf around Australia, very little coordinated research has been undertaken to date. In light of the scientific complexity of Bass Strait its resource potential both living and non-living, and its central position in relation to major population centres and shipping lanes, the Victorian Institute of Marine Sciences (VIMS) initiated a major study (VIMS 1978).

Early in 1978 VIMS set about to establish a Study Planning Committee to formulate proposals for such study. An invitation to participate in the project was extended to a wide number of organizations, institutions and individuals. The status of the responses varied substantially.

Significant study areas were outlined (VIMS 1978) as

1, bathymetry (1:250 000 mapping). 2, geological evolution and materials. 3, water movements and circulation. 4, atmospheric interactions. 5, chemical processes and transport. 6, sediment transport and geomechanics. 7, (a) continental shelf ecosystem—Plankton; (b) continental shelf ecosystem—benthic studies; (c) continental shelf ecosystem—fisheries. 8, coastal zone interactions. 9, the Bass Strait Islands. 10, continental shelf management and utilisation. 11, community interests and education.

For all topics except 1, 10 and 11 (for obviously different reasons) position fixing is an adjunct to the main task not an end in itself, and so should not dominate the operation. An ideal system would be one which covers the whole area of operations at all times, gives location to an accuracy that will satisfy the most exacting user, be largely automatic in operation and be of little cost.

### EXISTING FACILITIES (Table 1)

Traditional navigational aids (navaids), such as lead lights, radio direction finding (RDF), celestial navigation, radar and dead reckoning have been chosen not to be the subject of this paper. Bass Strait is well served for traditional shipping (Navigational Aids Systems Inquiry 1974) by these navaids and placed in skilled hands are accurate. Within Bass Strait there are four radio beacons, Cape Otway, Cape Schanck, Cape Wickham and Gabo Island as well as 29 attended and unattended lights. (Navigational Aids Systems Inquiry 1974).

The oil exploration industry has self contained Decca Trisponder, Motorola Miniranger systems to service its own requirements. The coverage is shown in Fig. 1.

Global navigation systems such as Omega (and hybrids) and satellite systems may be considered as existing facilities but are discussed further below.

### ALTERNATIVES

Traditional position fixing systems have been broadly classified (Ingham 1974) into

1, short range (25 to 100 km), 2, Medium range (150-1200 km), and 3, long range (>2000 km).

Many other classifications are possible; frequency, vertical (i.e. below surface, surface, airborne) or lattice propagation type. In this paper the latter classification is preferred.



TABLE 1  
EXISTING FACILITIES WITHIN BASS STRAIT\*†

VICTORIA	TASMANIA
<i>Manned Lighthouses</i>	
Cape Otway	Low Head
Cape Schanck	Swan island
Wilson's Promontory	Eddystone Point
Deal Island	
Point Hicks	
Gabo Island	
<i>Unattended Lights</i>	
Cape Wickham	Three Hummock Island
Currie Harbour	Hunter Island
Stokes Point	Highfield Point
Cumberland	Rocky Cape
Councillor Island	Table Cape
Split Point	Round Hill Point
Cape Liptrap	Mersey Point
Citadel Island	Waterhouse Island
Cliffy Island	Cape Barren
Hogan Island	Goose Island
	Cat Island
	Holloway Point

\* Information derived from Commission of Inquiry into the Maritime Industry. Report of navigational aid systems. 1974. Parliamentary Paper No. 319.

† The State division is one from the above Inquiry and not the geographical State boundary.

As an introduction to the basic principles of electromagnetic position fixing (EPF) this section is devoted to an explanation under:

1. Range-Range systems; 2. Rho-Rho systems; 3. Hyperbolic systems; 4. Satellite systems.

#### RANGE-RANGE (Table 2)

This is the most accurate mode (to this day) due to the strong geometry of the pattern of intersecting circles (Fig. 4). It must be pointed out however, that less accurate fixing may eventuate if the geometry is allowed to degenerate. A typical system consists of a ship borne master and antenna (R/T unit) propagating a microwave which is received by a shore station (slave unit or remote) and retransmitted back to the master. The round trip travel time is converted to a distance and two such distances define the ship's position. A limited number of vessels can use the same remote, generally one to five. The number of remotes is also restricted varying from manufacturer to manufacturer.

For Bass Strait the range-range solution is unfortunately manpower intensive. From tests conducted in February 1979, aboard the M.V. Cape Don three remote stations covered less than 1/6 of Bass Strait. The remotes were deployed at Arthur's Seat, Bass Hill and Mount Oberon (Wilson's Promontory). All range-range systems depend on line of sight conditions and range is proportional to elevation of both remote and master (R/T unit). It is not always possible (time and expense wise) to occupy the highest peak and a six hour rough walk (with remote and 3 12V DC batteries) into Mt. Latrobe was the reason for selecting Oberon. (See Fig. 2).

For a scientific study, range-range systems are not attractive unless the study is confined, laterally along the shoreline or to a limited distance from remotes (i.e. < 150 km). The expected coverage of a range-range system in Bass Strait is shown in Fig. 3. The coverage shown in Fig. 3 requires the occupation of 27 stations, 2 or 3 at any one time. An additional disadvantage of the range-range system is that the pattern cannot be monitored, although traditional surveying methods may be used to calibrate remotes. It is recommended that this calibration be carried out within the study area and over the approximate range of the survey. Dynamic test measurements have been proposed by others (Ridge 1973) as a method to lessen the effect of unknown refractive index and propagation speed.

#### RHO-RHO (Table 3)

These systems do not require the ship to carry a transmitter. Instead, the shipboard receiver and both shore transmitters are controlled by precise atomic frequency standards. Once synchronised in both rate and epoch with the shore transmitters, the receiver monitors phase change due to ship movement, which in turn is converted to change in range (which is added to the initial synchronised range). The measurement of range change, is, in this case, achieved proportional to a full wavelength change whereas in range-range systems it is half of a wavelength. Measurement accuracy may be slightly inferior to range-range because of very small differences in frequency of the atomic standards. Such systems are in world wide use particularly Loran-C and Decca Lambda. The pattern can be monitored at a stationary receiver on shore.

A draw back of this system, particularly with Telecom installations at Arthur's Seat and Mt. Oberon, lies in the several frequencies used. It has

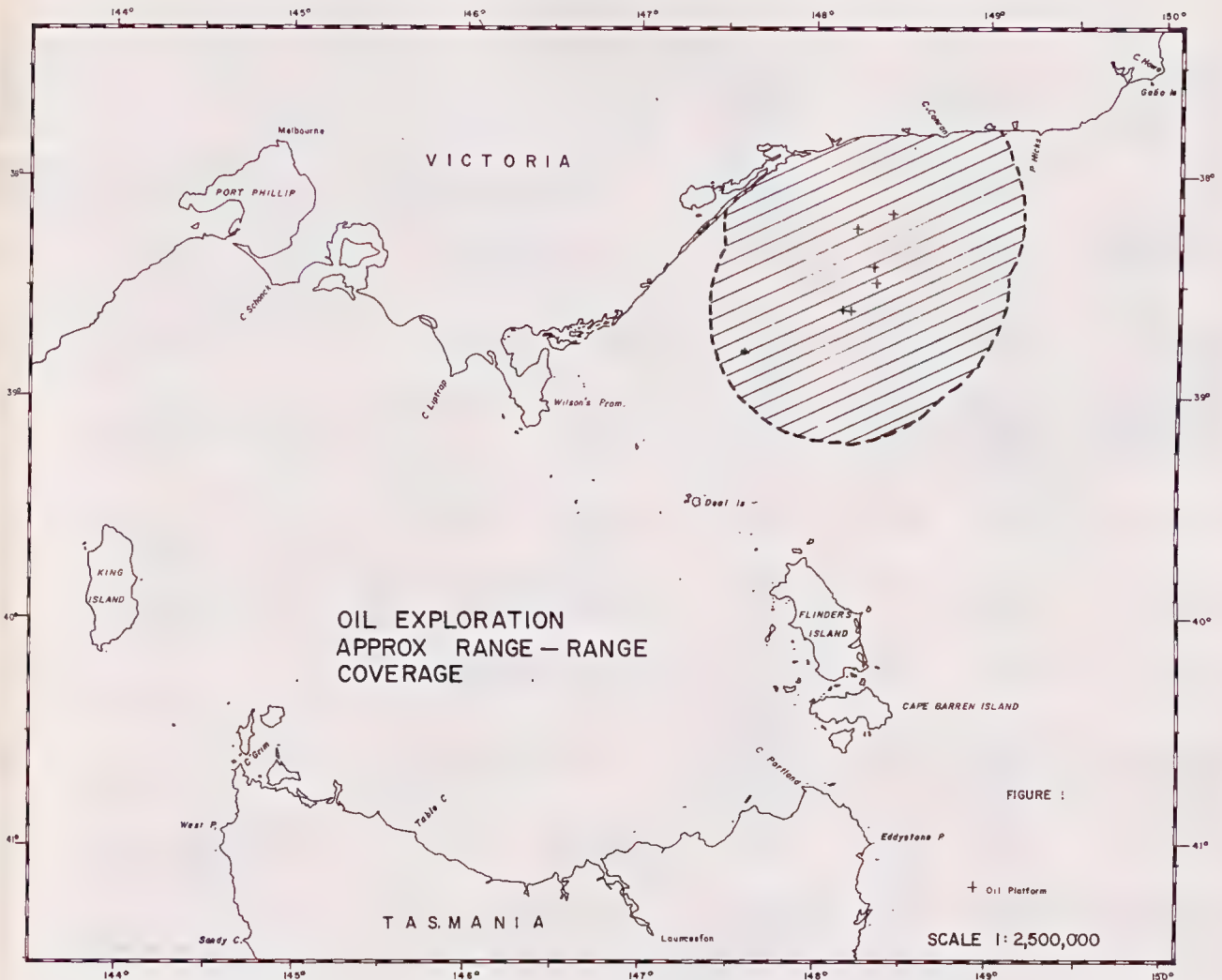


FIG. 1—Approximate coverage of oil exploration range-range system.

been stated (Cliff 1979) that it would not be possible to co-site such equipment with Telecom R/T facilities. Ultra High Frequencies, (UHF, 300-3000 MHz) generally do not cause interference co-sited, but the transmit power levels are much higher than existing co-sited UHF facilities and interference to Telecom services is possible. Equipment operating at High Frequencies (HF, 3-30 MHz), as a general policy, is not permitted at R/T stations. Operation of any system at "reasonable" separation from Telecom R/T sites would of course be satisfactory. Preference for Telecom sites is inferred here, due to geographic location and elevation, though the latter is of less importance.

#### HYPERBOLIC (Table 4)

In many ways similar to Rho-Rho and others have grouped them together (Leahy 1979, Ingham

1974). All three stations may be installed ashore, the ship requiring only a receiver to detect the difference in phase between the signals of master and slaves. The hyperbolic systems, although more complex in theory (Thomson) achieve some economics in practice even though three shore stations, a master and two slaves are involved. They are intrinsically multiuser systems. Position of constant phase difference for ranges from any set of master and slave units lie on a hyperbola. A family of these curves can be established (as with sextant graph sheets) and forms a "lattice" (for production of lattices, Royal Australian Survey Corps 1978), on which the ship's position can be tracked. The "lane" width of the lattice is not constant as can be seen from Fig. 4. The precision will deteriorate with lane width, which occurs with increase in distance from the shore stations. The pattern geometry is weak (intersection angle varies



TABLE 2  
RANGE-RANGE SYSTEMS

System	Range (km)		Number of uses	Frequency	Resolution	Precision	Principle	Used in Australia
	Day	Night						
ARGO	740	400	12	1.6-2MHz	0.01 lane	1.4 m (10 m)	Phase Comparison	Yes
AUTOTAPE	150 LOS	150 LOS	Single	3GHz	0.1 m	0.5 m $\pm 10^{-6}$	Phase Comparison	No
LAMBDA DECCA 12f	650	350	Single	150 KHz	0.01 lane	30-100 m	Phase Comparison	No
MINIRANGER III	185 LOS	185 LOS	10 time sharing	5 or 10 GHz	1 m	3 m	Pulse Measurement	Yes
MAXIRAN	650	650	6	420-450 MHz	1 m	3 m (11 m)	Microwave Ranging	No
MINIRAN	45 LOS	45 LOS	6	3 GHz	1 m	2 m	Microwave Ranging	Yes
RAYDIST	480	280	4 (Hyp. unlimited)	1.6-3.3 MHz	0.5 m	3 m	Phase Comparison	Yes
TELLURO- METER	250 LOS	250 LOS	1, 3 with time sharing	3 GHz	0.1 m	$1.5 \pm 3 \times 10^{-6}$	Phase Comparison	No
TRIDENT III	250 LOS	250 LOS	50 Max	400,600 MHz 1300 MHz	1 m	3 m	Pulse Measurement	No
TRISPONDER	80	80	4 with time sharing	9 GHz	0.5 m	3 m	Pulse Measurement	Yes

NOTE: In the preparation of Tables 2, 3 and 4:

1. Precision figures taken from manufactures notes. User figures given in (brackets).
2. Information derived from: Eaton 1975; Haugh 1975; Ingham 1974; Leahy 1979; Thomson; U.S. Department of Commerce, 1977.

TABLE 3  
RHO-RHO SYSTEMS

System	Range (km)		Number of uses	Frequency	Resolution	Precision	Principle	Used in Australia
	Day	Night						
LORAN-C	2000	2000	Unlimited	100 kHz	25 m	150 m	Pulse and CWPC	No
OMEGA	Complete		Unlimited	10-30 kHz	500 m	2-4 km (4-10 km)	CWPC	Yes

Decca 12 F Lambda and Miniranger III may also be used in Rho-Rho mode.  
CWPC = Continuous Wave Phase Comparison.

TABLE 2 (continued)  
RANGE-RANGE SYSTEMS

Notes	Supply voltage	Display	Max. platform speed	Cost	Users world wide
94 m lanes Hyp. (optional)	22-32 v DC 115/230 v AC	Power light. Digital display Alarm light. 24 hr. clock	20 kts or 80 kts (opt)	\$140 k	U.K., U.S.
so hyperbolic	12 v DC 24 v DC	NIXIE Tube display Vary display rate	160 kts	\$90 k	Iran, U.S., Venezuela
600 m lanes to-Rho—unlimited ers	Diesel powered			\$250 k	North Atlantic, North Pacific
	24-30 v DC 115/230 v DC	LED display etc.	> Mach 1	\$27 k	Canada, Denmark, Finland, Germany, Holland, Italy, Japan, South Africa, U.S.A., U.K.
	12 v DC 110 v AC	Gas discharge display Rack mountable	80 kts	\$76 k	U.S.
	12 v DC 115 v AC	Gas discharge Display Update rate 10/sec.	130 kts	\$28 k	U.S.
so hyperbolic		Power indicator lights Rotating dials	No limit (tested to MACH 2)	\$70 k	Denmark, U.K., U.S.
ceased here ne 1979	12 v DC	NIXIE Tube display Update rate 400/sec.	30 kts or 500 kts (option)	\$30 k	Canada, Denmark, Nigeria, Norway, Sweden, U.K., U.S.A.
	24 v DC 110/220 v AC	LED display	600 kts	\$90 k	France
	22-32 v DC	Variable intensity numatron display	> Mach 1	\$27 k	Worldwide

TABLE 3 (continued)  
RHO-RHO SYSTEMS

Notes	Supply voltage	Display	Max. platform speed	Cost	Users world wide
ot, maintained	110/220 v AC			Variable due to coverage	North Atlantic & North Pacific
o hyperbolic	110/220 v AC	Alarm, chart & roller lane count	500 kts	\$3 k (receiver)	Global





FIG. 2—Range-Range coverage with 3 remotes, VIMS cruise February 1979.

rapidly), but there is no limit to the number of users, and the receiver is much less expensive than a Rho-Rho receiver. All Medium Frequency (M.F., 300 KHz-3 MHz), Low Frequency (L.F., 30-300 KHz), and Very Low Frequency (V.L.F., 10-30 KHz) systems can be used in hyperbolic mode.

Omega possibly has the longest range of the hyperbolic systems. The seven existing Omega installations are in:

Argentina, Japan, Liberia, La Reunion (a French Island off the East Coast of Africa), Norway, Hawaii, U.S.A.—North Dakota. Construction of the eighth and final installation in East Gippsland is due to commence soon. The transmitted signals from one of the Omega stations can be visualised as a series of concentric circles or lanes. If it is

assumed that at each of these circles the phase angle of the received Omega signal is the same as the phase of the signal at the station transmitter, then the distance between the circles is proportional to the wavelength (16 nmi, for a 10.2 KHz transmission). One position fixing technique computes a position fix by intersecting the measured position within three such lanes from three Omega transmitters. In order to navigate, the Omega receiver must know the correct land number of each received Omega transmission.

"The stated accuracy goal of the Omega system is 1 nmi root mean square error (rms) probability during day conditions and 2 nmi rms at night" (Herbert 1977, Maenpa 1978). Navigation accuracy is often much less than this goal but it forms a very useful system, alone or as a satellite/Omega hybrid.

There are essentially three satellite navigation or positioning methods in use today (Hart 1968).

The Doppler method as developed for the U.S. Navy Navigation Satellite System. The system depends upon measurement of Doppler shift of a received satellite signal to produce a fix and the basis of the initial calculations is on an assumed position. The resultant precision is dependent upon the knowledge of orbital parameters on the first hand, while antenna placement, ship motion and reflected wave may also lead to a decrease in precision. Typical of the Doppler satellite navigators are those produced by Magnavox (Stansell 1978) and Decca.

The third basic method is that of ranging or trilateration between ground positions and the satellite. The U.S. Army's Sequential Coalition of Range (SECOR) (5) system requires specialized equipment but at this time is not planned to be used at sea.

All field operations of the navigators are extremely simple and the equipment consists of master unit (a receiver) and antenna/preamplifier. Geocentric coordinates are derived from doppler shift via the broadcast ephemeris (WGS72 datum). It will be recommended later that the Australian Map Grid (AMG) be the adopted co-ordinate datum for the study and consequently conversion from WGS72 to Australian Geodetic Datum (AGD) (hence AMG) must be known. Such conversions are available (Natmap 1978).

During the scientific cruise in February 1979 (Fig. 5) a Magnavox MX1107 was tested. Time in-





TABLE 4  
HYPERBOLIC SYSTEMS

System	Range (km)		No. of uses	Frequency	Resolution	Precision	Principle	Used in Australia
	Day	Night						
HI-FIX/6	350	350	Unlimited	1.6-5 MHz	0.01 lane	5 m	Phase Comparison	Yes
HYDROTRAC	450	220	Unlimited	1.6-3 MHz	0.8 m 0.01 lane	?	Phase Comparison	No
LORAC	480	160	Unlimited	1.6-2.5 MHz	0.001 lane	20-40 m	Phase Comparison	No
OM1 System	480	280	Unlimited	1.6-1.8 MHz	0.001 lane 0.2 m	1 m	Phase Comparison	No
SYLEDIS	120 LOS	120	Unlimited	420 MHz	0.1 m	1 m	Pulse Comparison	No
TORAN	550	250	Unlimited	1.6-3.0 MHz	0.01 lane 0.4-0.9 m	1 m	Phase Comparison	No

Raydist, Decca 12f Lambda, Argo may be used in Hyperbolic mode.  
LOS = line of sight.

tervals between acceptable passes, which are generally related to latitude, ranged from a few minutes to nearly 7 hours. This can place severe limitation on scientific sample rates and times. For continuous fixation in the dynamic situation the velocity vector must be supplied to the master (with microprocessor) and the solution is particularly sensitive to errors in this information for instance, 0.2 nmi per knot of speed error. In subsequent cruises updated Magnavox equipment returned time intervals of approximately 70-90 minutes (latitude, 39°S-40°S).

The advantages of a satellite navigator are that it is independent of shore stations, multi-user, all weather and with reasonably predictable precision. Manufacturers claim a standard deviation of fixation of around 100 m for a single frequency receiver and 37 m for the more sophisticated two channel systems. From experience (with single channel systems) this would seem very optimistic. It is recommended (Hatch 1976) that translocation is a method to achieve improved precision.

#### ACCURACY AND PRECISION

As outlined earlier the scientists require both precision and accuracy; accuracy in the first instance and thereafter for relocation precision. The

term standard deviation of location is a convenient means of comparison (bring both precision and accuracy into account). As a general "rule of thumb" for any shore-based positioning system the greater the distance from the shore the lower both accuracy and precision, and thus the higher the standard deviation. This can be demonstrated by the application of error ellipses. An alternative method is to plot "contours" of predictable errors (for a particular constant multiple of standard deviation). Such an example can be seen in Fig. 6 where in this case the reliability of a proposed Decca Navigator chain can be determined. It should be realized that this approach of mathematical modelling lends itself, with great ease, to a pre-analysis of a survey or proposed survey system. It does, however, presuppose that sources of error can be made to fit such a model (or vice versa).

#### CAUSES OF ERROR

It is not the purpose of this paper to discuss these in great detail, but rather to acquaint the reader, in the broad sense, with their origins and effects. As all positioning systems utilise radio waves, from UHF in the case of range-range systems to VLF in the case of Omega, any devia-

TABLE 4 (continued)  
RHO-RHO SYSTEMS

Notes	Supply voltage	Display	Max. platform speed	Cost	Users world wide
lanes also ge-Range	22-32 v DC	Power lights. Alarm lights. Filament type numeric indicator	460 kts	\$80 k	U.K., U.S., Canada, Finland, Germany, N.Z., Norway, Poland, Sweden, U.S.S.R.
g developed	22-30 v DC 115/230 v DC	Power lights. Digital display. Alarm, Hold, selected display	38 kts	\$80 k	U.K., U.S.
Range-Range lanes	115 v DC	Power lights, drum display long/lat direct	80 kts	\$185 k	U.K.,* U.S.
Range-Range	12 v DC 24 v DC	Power lights. Panel illumination.	80 kts 160 kts (opt)	\$150 k	New System—introduction
	22-30 v DC	LED display	190 kts	\$53 k	Denmark, France, Holland, Italy, Singapore, Spain, South Africa, U.K.
	22-30 v DC 110/220 v AC	NIXIE tube display Alarm lights	270 kts	\$60 k	Denmark, France, Iceland, U.K.

tion in wave path will adversely affect the measurement accuracy. In line of sight equipment (mostly range-range systems) this deviation is usually ground reflected waves. This will cause errors due to longer path length and/or cause the signal to be blanked out (often referred to as range holes). With long range systems it is the upper atmosphere and the so called skywaves that are important. Diurnal change in the ionosphere and the nightly disappearance of an absorbing layer just below it, cause significant interference problems to lower frequency radio measuring systems. This is apparent from Table 4 where most equipment has a diminished range at night.

As electromagnetic waves travel at the speed of light (i.e.  $299,792 \pm 12 \text{ m sec}^{-1}$  in a vacuum 1974) it is important to know or at least be able to determine this velocity. The velocity is affected by attenuation and retardation (the difference in velocity from in a vacuum to in another medium) which in turn are related to upper atmospherics (particularly the troposphere) and surface conductivity (refractive index).

As a consequence of the author's involvement with VIMS it is hoped that measurements of the velocity of propagation and/or related variables can be made in the field season, January to April

1980. Additional, but not all, sources of error are: a, Phase lag (for HF bands when paths are over land and sea); b, I11 directed antennae (Very High Frequency (V.H.F., 30-300 MHz); c, equipment with sector antennae); d, Ambiguities (hyperbolic systems); e, Solar radiation; f, Predicted Propagation Correction (PPC) (Omega); g, Velocity vector and orbital parameters (satellite sec. 4.6.7); h, Reliability of control coordinates; i, Accuracy of propagation frequencies; j, Zero or index error; k, Precision of lattice charts and corrections.

## THE REQUIREMENTS

Scientists have varying requirements on precision. However studies within the water column must eventually be closely related to bathymetry. The surveyor would be negligent if he did not attempt to achieve a precision such that bathymetric data is of use to both scientist and hydrographer (Cooper 1969). During the collection of water temperature and salinity data, precision may be less important. During the February 1979 cruise it was not uncommon to collect such data for 2 to 3 nautical miles. It was subsequently considered to have come from a point location. In dynamic mode this sampling continued around the clock.



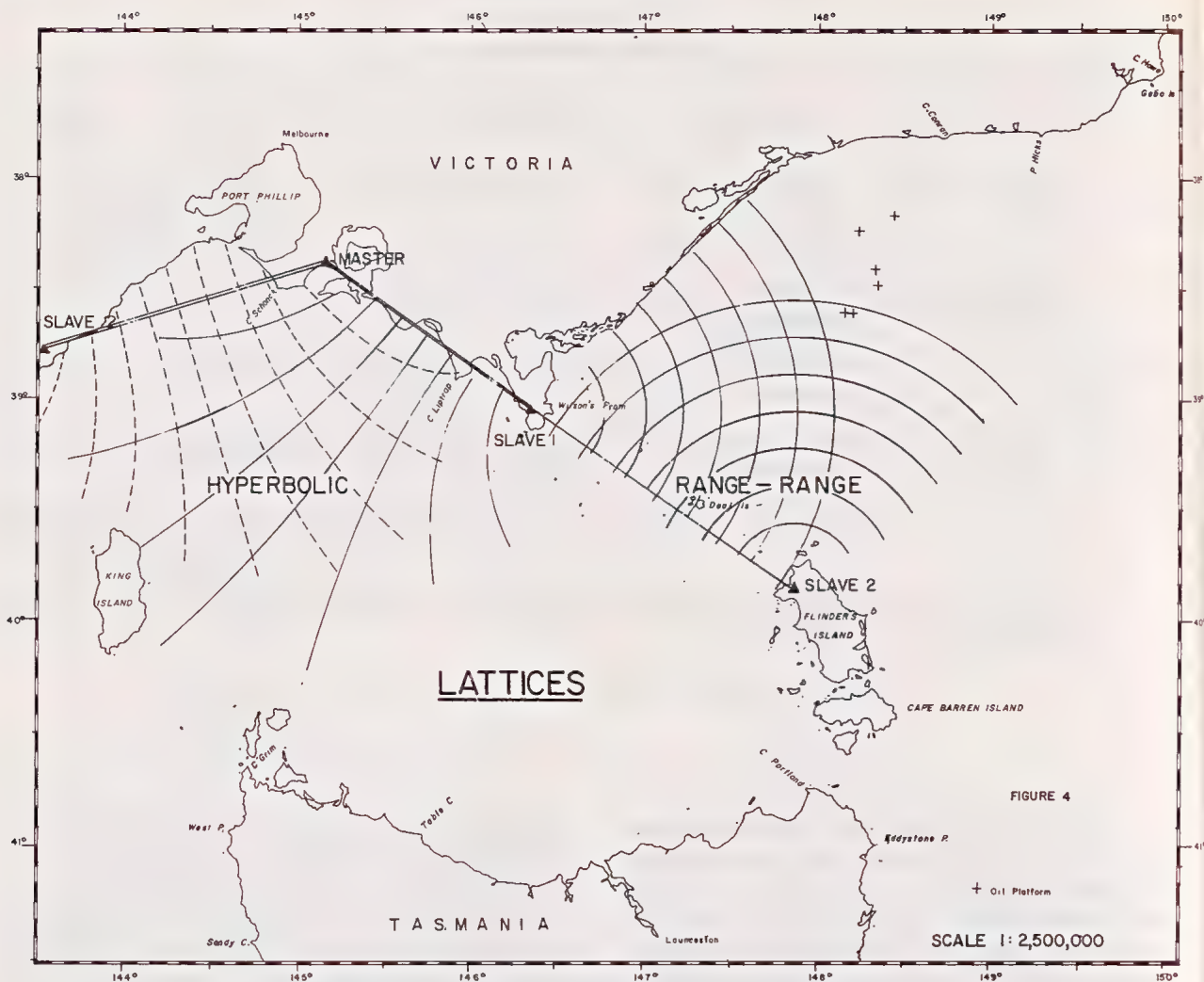


FIG. 4—Examples of Hyperbolic and Range-Range lattices.

The study (VIMS Report 1) ranges from the Victorian to Tasmanian coasts, from King to Flinders Islands. Coastal environments and island ecosystems will also form an important part of the study. For core and grab sampling, vertical water column sampling, sediment transport and others, precision in relocation will be of prime importance. For relocation and grid plotting real time coordinate determination is also important.

Therefore, the surveyor will have to provide a system (or hybrid system/s) that in turn provides the highest possible precision, 24 hour coverage, total area coverage, precision relocation and real time solutions. In more general terms (Thomson) the surveyor must consider; — a, the position accuracy required; b, the area in which the study is to be carried out (distance from shore, approximate depth of water, size of vessel likely to be

used, etc.); c, dynamic and/or post-mission positioning requirements; d, availability of shore control; e, interfacing requirements with other instrumentation (e.g. echo-sounder, side scan sonar, sub-bottom profiler, gravimeters, magnetometers, etc); f, position methods (e.g. geometry, quantities to be measured); g, duration of surveying operation and periods during which positioning is required (e.g. 24 hrs/day, all weather); h, the availability of necessary measurement instrumentation; i, the availability of necessary computational devices to compute positions (and plot them) and/or accuracy estimates; j, cost, both capital and running.

#### THE FUTURE

The system that is finally adopted will more than likely be determined from a compromise be-

tween cost and efficiency. Up to now positioning has been determined by satellite navigator (kindly lent by Hawker Pacific Pty. Ltd.) but even here the scientists have reservations. To quote a VIMS report (79-K-1):

'The Sat Nav system still requires manual velocity and heading input, and is thus open to errors arising from lack of communication or corrupted data. An automatic log/gyro system would function more reliably. Some parts of Bass Strait experience very strong tidal streams. It is pointed out that no Sat Nav system (without Doppler Sonar) can allow for these disturbances continuously. Accordingly, optimum position location requires some long distance range-range system (ARGO or DECCA Navigator). The ultimate would be a network chain of some kind but in the current political and economic climate this utopia is

beyond the horizon. In the meantime, a range-range system (VIMS and the University of Melbourne now jointly own a Miniranger III with processing and plotting facilities) could be used for close in shore details and the Satellite navigator could be used (updated and automated) for general positioning and longer range work.'

The VIMS report (79-K-1) continues: 'For navigation the ship's navigator used AUS 358 Wilson's Promontory to Point Hicks and Flinders Island, published by the Hydrographic Service R.A.N. This chart has spot soundings in fathoms and a scale of 1:300 000. Some of the data on this chart are inaccurate, particularly in depths greater than 100 fm.'

If the data collected on VIMS cruises is to be used by others it is essential that a data bank be established. The value of same is well known. It

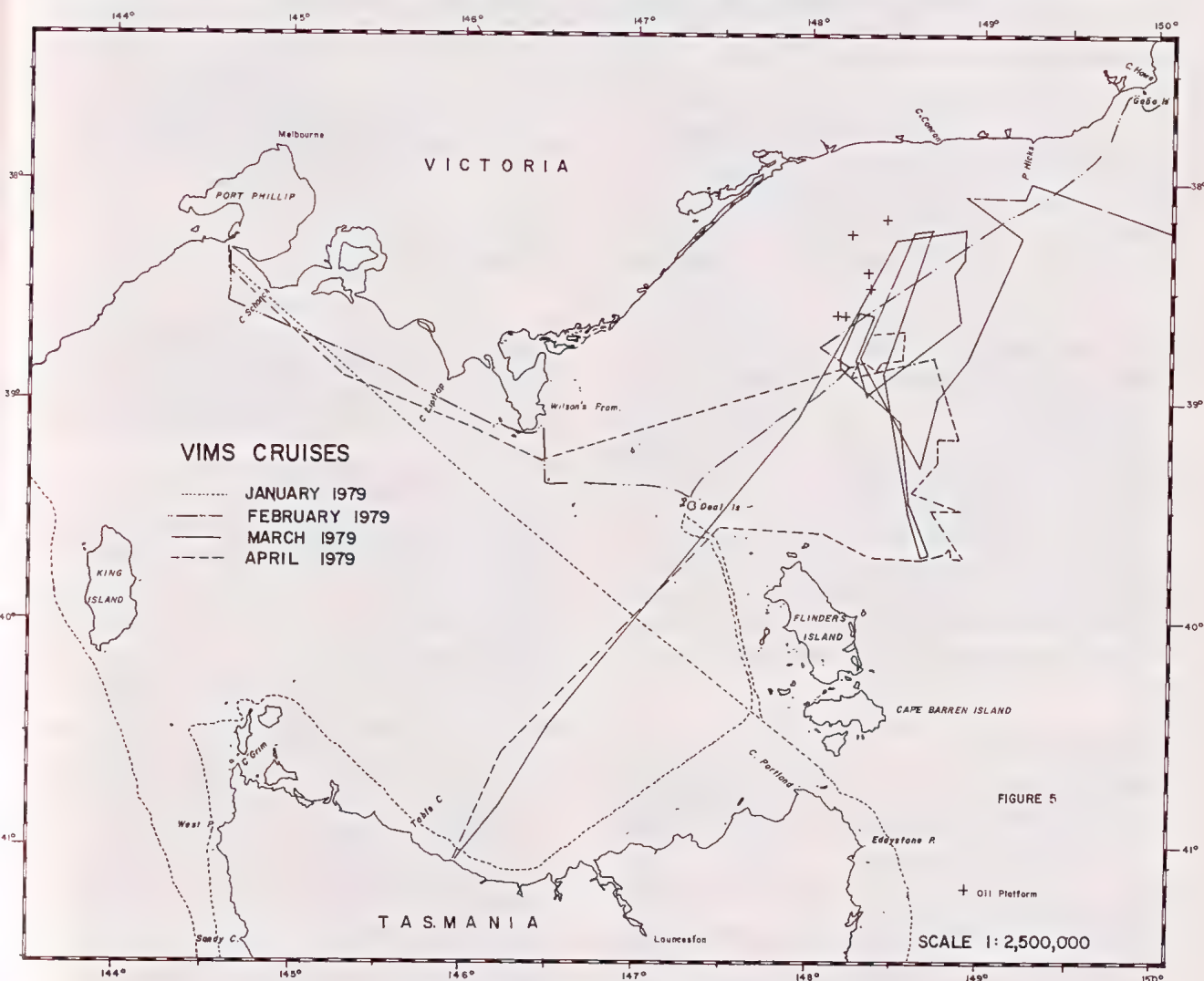


FIG. 5—VIMS cruise patterns 1979.



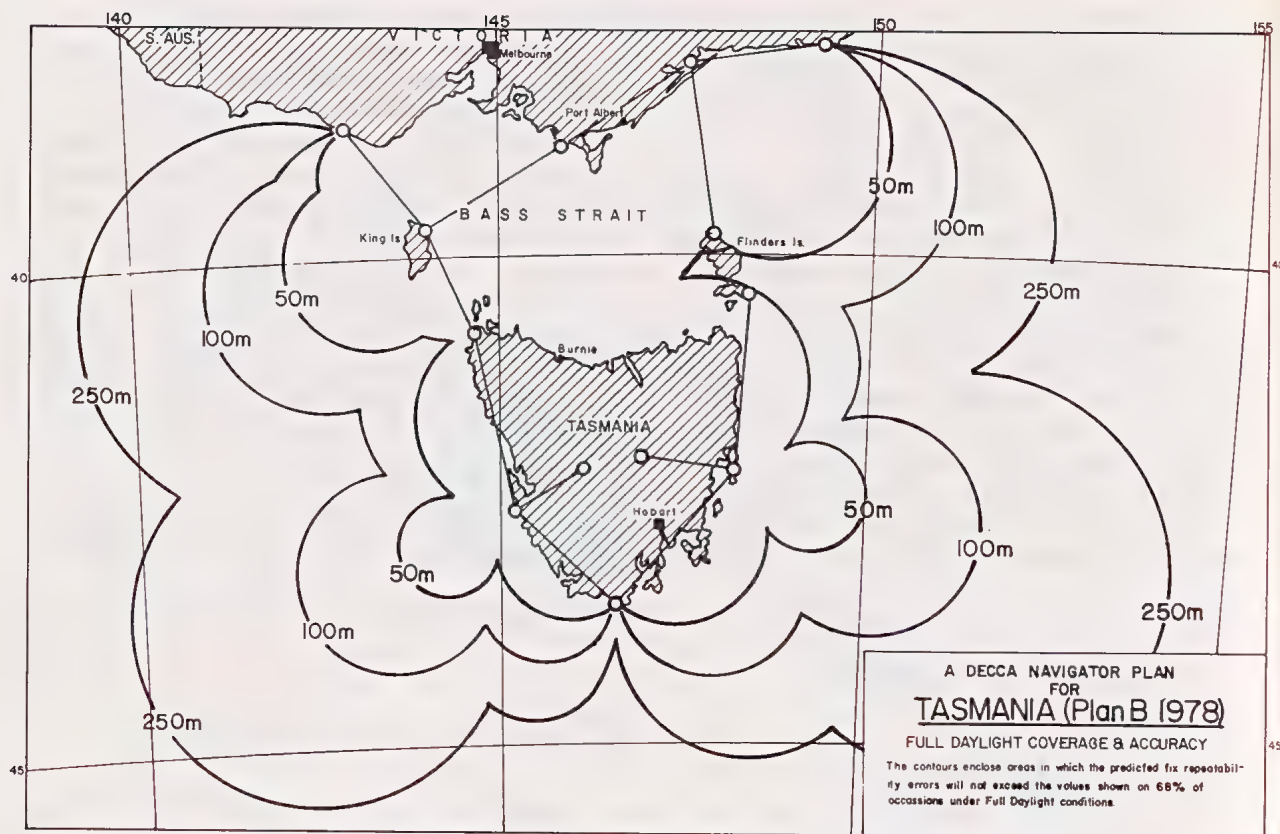


FIG. 6—Proposed Decca Navigator Chain. Error Quantities.

has been suggested that a geocoded system, maintained on a minicomputer, would amply suit. The system should be designed to catalogue, store and retrieve data. It would also locate material samples and prevent duplication of collection and analysis and render data more readily available to others. To this end, a geocoded data bank, AMG coordinates would be the logical choice (by the surveyor anyway) as the unique position identifier. Unfortunately, though agreeing in principle, the scientists involved question the usefulness of such a system, especially one based on coordinates.

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## DISTRIBUTION AND SUMMER STANDING CROP OF SEAGRASSES AND MACRO-ALGAE IN WESTERN PORT, VICTORIA

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**ABSTRACT:** The distribution of seagrasses and macro-algae in Western Port was mapped from aerial photographs and observations made by SCUBA diving. The angiosperm, *Heterozostera tasmanica*, was the dominant macro-benthic plant in Western Port accounting for 54% of the area covered by seagrasses and macro-algae. The angiosperms *Amphibolis antarctica* (8% of the area) and *Zostera muelleri* (16%), and the alga *Caulerpa cactoides* (19%) were also common. Above sediment biomass of these plants was estimated during summer by stratified cluster sampling in each of five segments of the bay. Within beds of seagrasses and macro-algae organic weight of all plants averaged 168 g/m<sup>2</sup>. The seagrass, *A. antarctica*, occurred only in the Western Entrance segment where above-sediment organic weight averaged 514 g/m<sup>2</sup>. The largest area of seagrasses and macro-algae was in the northern section of Western Port where large intertidal areas were covered by extensive stands of *H. tasmanica*. Algae made up 27% of the total macro-benthic standing crop in the bay and dominated the vegetation in the eastern segments of Western Port.

### INTRODUCTION

Western Port is a 680 km<sup>2</sup> coastal inlet off Bass Strait located 50 km south-east of Melbourne, Victoria. Extensive beds of seagrasses and benthic macro-algae have been reported in the bay and studies on fish, birds and other fauna have indicated that these macro-benthic plants are important to the Western Port ecosystem (Loyn & Bingham 1978, Robertson 1977, Robertson & Howard 1978, Smith *et al.* 1975).

McRoy and McMillan (1977) have reviewed the literature on seagrass standing crops. Their figures indicate a range for temperate species from 6 to 5160 g dry weight per m<sup>2</sup> with means ranging from 89 to 1900 g/m<sup>2</sup>. Within Australia, standing crops have been estimated for *Posidonia australis* in Cockburn Sound, Western Australia (Cambridge 1975) and in Botany Bay, New South Wales (Larkum 1976), and for several seagrasses in Tin Can Inlet and Moreton Bay, Queensland (Dredge *et al.* 1977, Kirkman 1978). The standing crops for various macro-algae in South Australia have also been determined (Shepherd & Womersley 1970, 1976). However, there are no published estimates of the standing crop of any seagrasses along the southern Australian coast. The objectives of this study were to determine the distribution of the

dominant macro-benthic plants in Western Port and to estimate their summer standing crops.

### METHODS

The seagrasses and macro-benthic algae of Western Port were mapped at a scale of 1:15 000 by Natural Systems Research Pty. Ltd., from colour aerial photographs taken at a height of 2290 m during 1973 and 1974 and from field checking carried out in July 1974 (unpublished report to the Western Port Bay Environmental Study, Ministry for Conservation, Victoria). These maps were modified in the present study using the results of a preliminary survey in December, 1974. This preliminary survey indicated that all of the area of Western Port covered by macro-benthic plants could be divided into five classes on the basis of the dominant species. An area designated as dominated by one species could contain small patches (up to 3 ha) of other species and/or low densities of minor species mixed with the dominant. In order to estimate distribution, Western Port was divided into five segments as in Harris *et al.* (1979): Western Entrance, Lower North Arm, Upper North Arm, Corinella Segment and Rhyll Segment (Fig. 1). All areas with seagrasses and macro-algae were thus divided into 25 categories



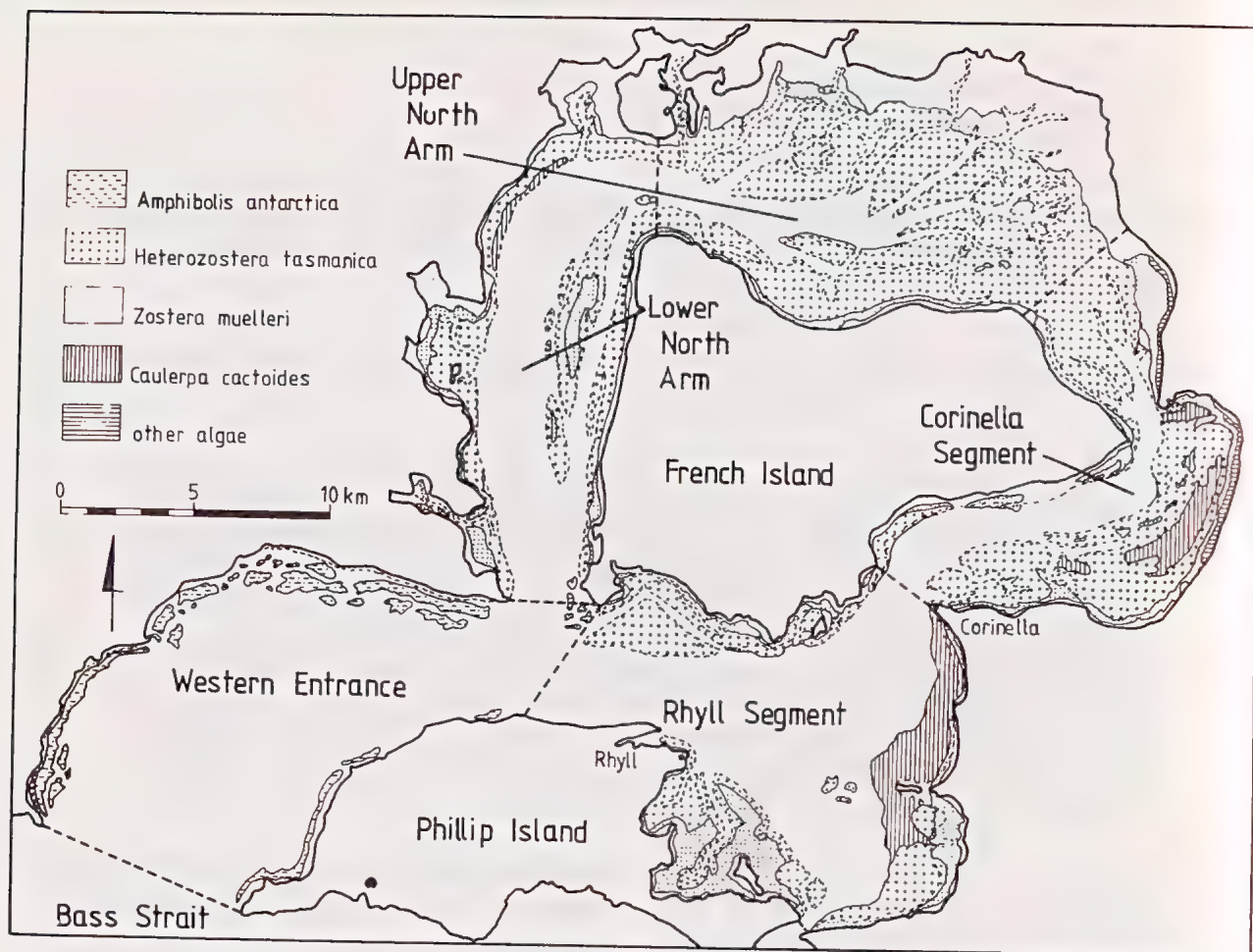


FIG. 1—Distribution of seagrasses and macro-algae in Western Port. Sections of the bay from Harris *et al.* 1979.

or strata, defined by the segment of the bay in which it occurred and the plant that was dominant. The area of each of these strata was determined to the nearest hectare.

Most estimates of seagrass and macro-algal standing crop are based on a 'random' series of samples taken within pre-selected beds of seagrass and/or macro-algae. Extrapolation of the dry or fresh weight means thus obtained to include the total area estimated for the respective plant is fraught with uncertainty and lacks any method of defining the reliability of the estimate. In order to overcome these problems, stratified cluster sampling (Yamane 1967) was used in this study. Confidence limits could then be placed on all estimates of standing crop. Within each section of the bay 30 to 40 primary sampling sites of 2500 m<sup>2</sup> were allocated in proportion to the amount of area in each stratum. These primary sampling sites and the two or three samples within each site were randomly selected. Sample size was 0.0625 m<sup>2</sup>, which

size had the lowest variance/mean ratio of sample sizes ranging from 0.003 91 m<sup>2</sup> to 0.25 m<sup>2</sup> in a preliminary test (Kershaw 1973).

The standing crop of seagrasses and perennial marine macro-algae in temperate climates usually fluctuates seasonally with a maximum in summer (Sand-Jensen 1975). This is also true for *Heterozostera tasmanica* in Western Port (Bulthuis, unpublished data). Field samples therefore were collected in mid-summer, January, 1975, when standing crops would be expected to be near their annual maxima. Sampling sites were located in the field by ship-borne radar and hand-held compass with reference to charted beacons and landmarks. All macro-benthic plants within the sampling area were cut at the mud surface, placed in a plastic bag and kept on crushed ice for transport.

All samples were stored at 5°C in the laboratory until sorted. Within four days of collection the samples were washed free of sediment and detritus, divided into angiosperms and algae, and

dried at 105°C to constant weight. The living, dead and detrital stems of *H. tasmanica* were indistinguishable from each other and removed from the sample. Therefore, sixty additional samples of *H. tasmanica*, with the sediment intact, were taken to the laboratory where living stems and leaves were carefully sorted from the remainder of the sample. Linear regression of leaf dry weight against leaf plus living stem dry weight of these samples was used to estimate leaf plus living stem dry weight of all *H. tasmanica* samples. Subsamples of each sample greater than 1 g (which included about 70% of the samples) were muffled in pre-heated aluminium foil at 550°C to constant weight. The percent ash-free dry weight or organic weight (Westlake 1963) of each subsample was used to calculate the total organic weight of the sample.

The total organic weight of seagrasses and macro-algae in each stratum and segment of the bay with its variance and 95% confidence limits was calculated by the formulae for stratified cluster sampling analysis in Yamane (1967).

## RESULTS

Three seagrass species, *Amphibolis antarctica* (Labill.) Sonder & Aschers., *Heterozostera tasmanica* (Martens ex Aschers.) den Hartog and *Zostera muelleri* Irmisch ex Aschers., and one species of algae, *Caulerpa cactoides* (Turner) C. Agardh (Chlorophyta), dominated the macro-benthic vegetation in Western Port. In addition to strata dominated by these four species, a fifth stratum in each segment of the bay included areas dominated by algae other than *C. cactoides*. Numerous species of algae and other seagrasses were present in each stratum in addition to the dominant species. For example, *Zostera muelleri* was frequently present in the *Heterozostera tasmanica* areas, and *H. tasmanica* and *Caulerpa cactoides* formed mixed communities in the Corinella segment. The seagrass, *Haslophila ovalis*

(R. Br.) Hook. f., occurred in small patches in most strata. Various algae were common in the seagrass strata including *Polysiphonia* sp., *Caulerpa sedoides* (R. Brown in Turner) C. Agardh and *Jeanerettia* sp. *Asperococcus bulbosus* Lamouroux and *Enteromorpha* sp. were present in most of the *Heterozostera tasmanica* areas of the Upper North Arm. Coralline algae were especially prominent growing on *Amphibolis antarctica*.

Seagrasses and macro-algae were distributed throughout Western Port covering a total of 251 km<sup>2</sup> or 37% of the bay's area (Fig. 1, Table 1). *Heterozostera tasmanica* was the dominant plant, accounting for 54% of the total area occupied by seagrasses and macro-algae. *Caulerpa cactoides* (19%), *Zostera muelleri* (16%) and *Amphibolis antarctica* (8%) covered most of the remaining area. Strata dominated by algae other than *Caulerpa cactoides* accounted for less than 3% of the area. Each segment did not have all species present. The algae dominated strata were mainly on the eastern side of the bay in the Corinella and Rhyll segments. In the Western Entrance the only macro-benthic plant covering more than 0.1 km<sup>2</sup> was *Amphibolis antarctica* and this species was rare in the other sections of Western Port. The Upper North Arm had the largest area of seagrasses and macro-algae while the Western Entrance had the smallest area.

Mean organic weight of the standing crop varied from 39 to 66% of the total dry weight for different plant species (Table 2). The algae had a lower percentage organic weight than did the angiosperms.

Organic weight per square metre at any one primary sampling site (mean of two or three samples) varied from zero to 431 g in *Heterozostera tasmanica* dominated strata, from zero to 333 g in the *Caulerpa cactoides* strata and from 218 to 706 g in the *Amphibolis antarctica* strata. The mean values presented in Table 3 indicate large differences between strata dominated by the

TABLE 1  
AREA (KM<sup>2</sup>) DOMINATED BY SEAGRASSES AND MACRO-ALGAE IN EACH OF FIVE SEGMENTS OF WESTERN PORT AS ESTIMATED FROM AERIAL PHOTOGRAPHY AND FIELD SAMPLING

Segments	<i>A. antarctica</i>	<i>H. tasmanica</i>	<i>Z. muelleri</i>	<i>C. cactoides</i>	Other algae	Total
Western Entrance	20.6	<0.1			<0.1	20.6
Lower North Arm	<0.1	20.4	9.6	4.5	<0.1	34.5
Upper North Arm		61.6	16.2	2.8	<0.1	80.6
Corinella Segment		29.1	4.6	23.9	1.0	58.6
Rhyll Segment		25.2	9.4	17.2	4.8	56.6
	20.6	136.3	39.8	48.4	5.8	250.9



TABLE 2

MEAN ORGANIC WEIGHT AS PERCENTAGE OF TOTAL DRY WEIGHT IN SEAGRASSES AND MACRO-ALGAE FROM WESTERN PORT

Plant	Mean	s.e.	n
<i>A. antarctica</i>	66.0	± 2.16	12
<i>H. tasmanica</i>	65.4	± 2.43	85
<i>Z. muelleri</i>	47.2	± 1.62	52
<i>C. cactoides</i>	42.9	± 1.19	25
Other macro-algae	39.0	± 1.01	90

same species but located in different sections. These differences may indicate the suitability of the various sections for growth of the respective plants. Algae varied in importance within the angiosperm beds. In the *Heterozostera tasmanica* strata of the Rhyll Segment the organic weight of algae was nearly as large as the angiosperm weight, principally *Jeanerettia* sp., caught among the stems of *Heterozostera tasmanica*.

The mean organic weight per unit area and the area of coverage was used to estimate the total standing crops of seagrasses and macro-algae in Western Port (Table 4). *Heterozostera tasmanica* accounted for 58% of the total standing crop.

The upper North Arm had the highest standing crop followed by the Western Entrance and the Rhyll Segment. The total standing crop for the whole of the bay is 42 000 tonnes of organic weight which is equivalent to 61.8 g/m<sup>2</sup> averaged over the whole bay. The total dry weight was 85 100 tonnes or 125 g/m<sup>2</sup> averaged over the bay. When the algae present in the angiosperm dominated areas is added to the *Caulerpa cactoides* and "other algae" strata, the total organic weight of algae in the bay is 11 500 tonnes (27% of 42 000) compared to 30 500 tonnes (73%) for the angiosperms.

## DISCUSSION

The distribution of seagrasses and macro-algae in Western Port reflects the sediments and bottom topography. The sediments of the Western Entrance are sandy and the coast is exposed to southerly winds and swell from Bass Strait. In this section of Western Port the primary macro-benthic plant is *Amphibolis antarctica* which according to den Hartog (1970), is generally found on "sandy bottoms . . . where the water is kept in continual motion by currents or wave action". *A. antarctica* did not occur, except in very small isolated patches, in the remaining sections of Western Port where bottom sediments, other than

in the channels, are generally muddy. Excluding the Western Entrance, the distribution of seagrasses and macro-algae closely paralleled the intertidal area (Fig. 1). Thus, the Upper North Arm which has the largest intertidal area also had the largest area of seagrass and macro-algae (Table 1). *Heterozostera tasmanica* was the main macro-benthic plant on the intertidal mudflats with *Zostera muelleri* generally occurring higher in the littoral zone than *Heterozostera tasmanica*. *Caulerpa cactoides* usually occurred in the subtidal areas and only occasionally was present in shallow depressions in the intertidal zone. *C. cactoides* was thus found mainly in the Corinella and Rhyll Segments where there are large subtidal areas with a muddy sediment.

Most published reports of seagrass standing stocks are in terms of total dry weight including roots and rhizomes (McRoy & McMillan 1977). If the leaf dry weight data from this study is corrected to include roots (leaf dry weight × 1.65; McRoy 1970) the mean total biomass per m<sup>2</sup> during summer is estimated as 1100 g for *Amphibolis antarctica*, 460 g for *Heterozostera tasmanica* and 150 g for *Zostera muelleri*. This range of means is similar to the range of means, reported for *Zostera marina* (McRoy & McMillan 1977).

Westlake (1963) in his review of plant produc-

TABLE 3  
STANDING CROP (ORGANIC WEIGHT IN G/M<sup>2</sup>) OF SEAGRASSES AND MACRO-ALGAE IN FIVE SEGMENTS OF WESTERN PORT IN JANUARY, 1975 (MEAN ± S.E.)

Plant and Segment	Angiosperm	Algae	n
<i>A. antarctica</i> stratum			
Western Entrance	469 ± 70.0	46 ± 12.0	18
<i>H. tasmanica</i> strata			
Lower North Arm	139 ± 16.8	26 ± 5.2	63
Upper North Arm	190 ± 21.5	33 ± 6.8	50
Corinella Segment	54 ± 14.6	34 ± 6.8	26
Rhyll Segment	112 ± 31.9	80 ± 25.2	18
<i>Z. muelleri</i> strata			
Lower North Arm	36 ± 6.3	1.4 ± 0.74	27
Upper North Arm	32 ± 14.1	11.1 ± 3.54	10
Corinella Segment	7.9 ± 2.99	14.9 ± 4.81	6
Rhyll Segment	71 ± 23.2	3.6 ± 1.48	18
<i>C. cactoides</i> strata			
Lower North Arm	39 ± 12.7	54 ± 29.3	9
Corinella Segment	0.9 ± 0.43	66 ± 14.8	14
Rhyll Segment	< 0.1	134 ± 27.5	18
<i>Other macro-algae</i> stratum			
Corinella Segment	0.4 ± 0.20	68 ± 26.2	8

TABLE 4

TOTAL STANDING CROP OF SEAGRASSES AND MACRO-ALGAE IN FIVE SEGMENTS OF WESTERN PORT IN JANUARY, 1975  
(ORGANIC WEIGHT IN TONNES  $\div$  100)

Segments	<i>A. antarctica</i>	<i>H. tasmanica</i>	<i>Z. muelleri</i>	<i>C. cactoides</i>	Other macro-algae	Total	95% Confidence Limits
Western Entrance	106					106	69.9-142
Lower North Arm		33.7	3.6	4.2		41.5	29.5-53.5
Upper North Arm		138	7.0	2.6		147	113-181
Corinella Segment		25.7	1.0	15.9	3.3	43.4	26.7-60.0
Rhyll Segment		48.3	7.0	23.1	0.7	81.8	52.2-111
Total	106	245	18.6	45.8	4.0	420	
95% Confidence Limits	69.9-142	200-291	9.7-27.5	29.0-62.6	1.0-7.0		

tivity recommended that organic weight be adopted as the best general criterion of productivity. This has been used in the present study. The standing crop determined in this study was the above-sediment portion of the angiosperms and algae. The estimates of total organic weight in Table 4 indicate that *H. tasmanica* is the most important primary producer among the seagrasses and macro-algae. The stems of *Amphibolis antarctica* are perennial so the standing crop of this seagrass may include several years of growth. The high standing crop of this species, therefore, may be due to its particular growth habit rather than to a relatively high net productivity compared with the other macro-benthic plants in Western Port. The Upper North Arm has the highest standing crop in the bay and therefore probably makes the greatest contribution to baywide macro-benthic plant production. The Western Entrance and the Rhyll Segment are also important in terms of production.

Algae are an important component of the seagrass beds in Western Port as indicated by the proportion of total organic weight attributable to them (Table 3). Algae both within the seagrass beds and in extensive beds of their own, increased in importance in the eastern section of Western Port where they accounted for 62% and 57% of the organic weight in the Corinella and Rhyll Segments respectively.

## CONCLUSIONS

1. *Heterozostera tasmanica* is the most important macro-benthic plant in Western Port, covering the greatest area and having the highest standing crop, 24 500 tonnes organic weight, and averaging 180 g/m<sup>2</sup>.

2. *Amphibolis antarctica* has a total standing crop of 10 600 tonnes averaging 515 g/m<sup>2</sup> and occurs mainly in the Western Entrance of Western Port.

3. *Zostera muelleri* generally occurs higher in the littoral zone than *Heterozostera tasmanica*, averages 46 g/m<sup>2</sup> and has a total of 1860 tonnes organic weight in Western Port.

4. Algae form a significant proportion of the standing crop of macro-benthic plants and are the main plants on the eastern side of Western Port where *Caulerpa cactoides* occurs in large beds, averaging 95 g/m<sup>2</sup> with a total standing crop of 4580 tonnes/organic weight.

## ACKNOWLEDGEMENTS

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# OBSERVATIONS ON THE FACTORS CONTROLLING THE REPRODUCTION OF TWO COMMON SPECIES OF BROWN ALGAE, *COLPOMENIA PEREGRINA* AND *SCYTOSIPHON* SP. (SCYTOSIPHONACEAE), IN VICTORIA

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**ABSTRACT:** Observations of seasonal changes in the mode of reproduction of *Colpomenia peregrina* (Sauvageau) Hamel and the complanate form of *Scytosiphon* in Victoria have been collected over several years. They are consistent with the results of experiments testing the effects of temperature and daylength on the reproduction of cultured plants which show that these environmental factors determine whether thalli give rise to similar (gametophytic) progeny or to the alternative sporophytic phases of the heteromorphic life histories. Such changes in the mode of reproduction form the basis of the seasonality of the larger gametophytes.

Sexual reproduction is a rare winter occurrence in both species, but experiments indicate that it is not simply controlled by temperature/daylength conditions. In culture, in conditions which favour the production of sporophyte progeny, *Scytosiphon* gametophytes began to release zooids at an age of 8-10 weeks but they showed no signs of sexuality; later, after 14 weeks, functional gametes were produced. The association of sexual maturity with age, a phenomenon previously unknown in this group of algae, helps to explain the elusive nature of sex in wild populations and its occurrence several months after the onset of the main growing season in autumn.

## INTRODUCTION

*Colpomenia peregrina* (Sauvageau) Hamel and *Scytosiphon* sp. are brown algae with complex heteromorphic life histories. The well known saccate and complanate thalli are the gametophytic generations and under certain conditions they produce the small and inconspicuous crustose sporophytic generations. Gametophytes of both species are common in the intertidal region of Victorian coasts from May to November, and fertile plants can be found throughout this period. The gametophytes show seasonal changes in their mode of reproduction. During May and June they produce zooids which develop into more gametophytes, but from mid-June to September the majority of zooids give rise to crustose sporophytes. During September *C. peregrina* reverts to gametophyte production (Clayton 1979). A small proportion of the *Scytosiphon* sp. population also produces gametophytic progeny at this time of year, but the majority produce sporophytes. The *Scytosiphon* sp. gametophytes die out altogether in December (Clayton 1976b, 1980). The results of several years of observations

on the reproduction of the two species (Figs 1 & 2) illustrate these seasonal changes.

(Note: *Scytosiphon* sp. refers to the taxon *S. lomentaria* var. *complanata* Rosenvinge. In Australia it has a life history which also includes a cylindrical form resembling *Scytosiphon lomentaria* (Lyngbye) Link (Clayton 1976a, b). Its taxonomic status is discussed in Clayton 1980.)

Experiments on the effects of daylength and temperature on the reproduction of cultured *Scytosiphon* sp. gametophytes indicated a possible basis for the seasonal changes outlined above. In daylengths of 8 hours some strains consistently reproduce gametophytic generations. Daylengths of 10 hours and longer induce sporophyte production, although gametophytic progeny were occasionally produced in daylengths of 12 hours. These responses of cultured *Scytosiphon* sp. to daylength are in broad agreement with the changing pattern of reproduction of wild *Scytosiphon* sp. and the corresponding seasonal changes in daylength (Figs 2 & 3). It may therefore be inferred that daylength is an important factor controlling reproduction in this species (Clayton



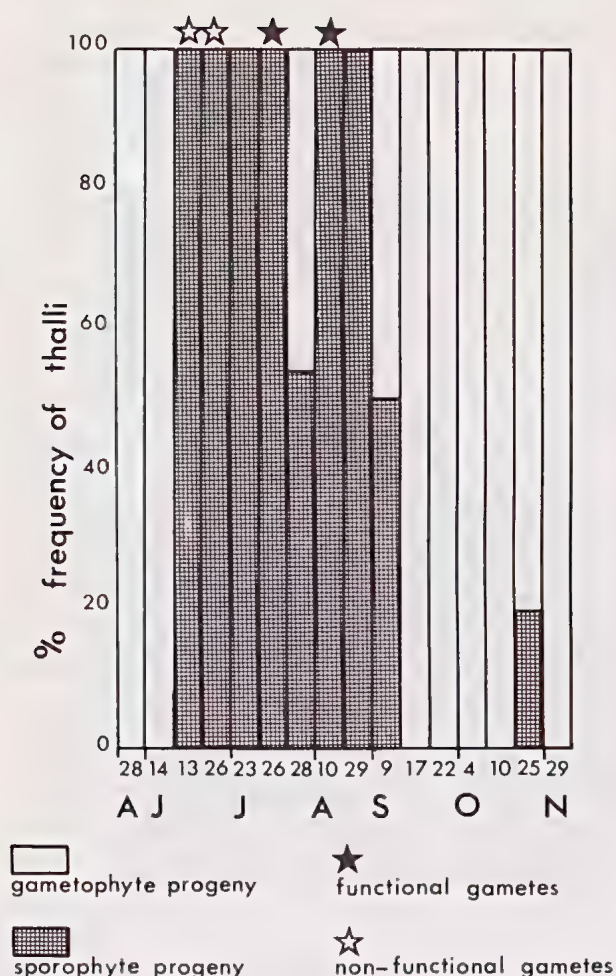


FIG. 1.—*Colpomenia peregrina*—seasonal changes in the percentage frequency of wild thalli producing gametophytic and sporophytic (or predominantly sporophytic) progeny.

1976b, 1980). A comparable influence could not be attributed to temperature.

A parallel series of observations on the effects of temperature and daylength on the reproduction of *C. peregrina* were carried out in order to compare the control of reproduction in a species having a different seasonal cycle from *Scytosiphon* sp. The results are described in this paper.

Sexual reproduction, which involves mating between anisogametes, is a rare winter occurrence in both species. Gametes are formed by some of those gametophytes which give rise to sporophytic progeny (Figs 1 & 2). Amongst cultured plants mating has only been observed a few times. *Scytosiphon* sp. produced gametes in cultures grown at 12°C, L:D 10:14 and 12:12h, and 14°C, L:D 10:14h, but only a relatively small proportion of the zooids were functional gametes (Clayton

1980). These results indicate a possible relationship between 'winter' conditions and gamete formation in *Scytosiphon* sp., but both the rarity and the variable success of mating reactions suggest that other factors are involved. A series of observations was designed to investigate another factor which might affect gametogenesis namely the age of the parent individual. *Scytosiphon* sp., rather than *C. peregrina*, was selected as a subject for this study as a greater number of cultured strains of known sex were available.

## METHODS OF INVESTIGATION

### CULTURE METHODS

All cultures were grown in Provasoli's ES medium (Wynne 1969) prepared using millipore-filtered seawater, which was changed at intervals of approximately two weeks. Except where specifically mentioned, culture dishes (Pyrex No. 3250) containing about 150 ml medium were used. Overhead lighting was supplied by Sylvania Gro-lux wide spectrum fluorescent tubes giving a quantum irradiance of 60-70  $\mu\text{E cm}^{-2} \text{s}^{-1}$ .

### THE EFFECTS OF TEMPERATURE AND DAYLENGTH ON THE REPRODUCTION OF *C. PEREGRINA*

The range of conditions investigated (Table 1) was chosen to include the temperatures and daylengths prevailing during the main growing season of *C. peregrina*, from autumn to early summer (Fig. 3). Initially four different strains

TABLE 1  
*COLPOMENIA PEREGRINA*—THE PERCENTAGE OF SPOROPHYTES IN THE PROGENY OF FOUR STRAINS CULTURED IN VARIOUS TEMPERATURE/DAYLENGTH REGIMES

	Strains			
Temperature/Daylength	1	2	3	4
12°C L:D 10:14h	100	89	0	43
12°C L:D 12:12h	>99	81	100	100
14°C L:D 10:14h	>99	97	0	>99
14°C L:D 12:12h	93	100	0	0
16°C L:D 8:16h	93	100	0	0
16°C L:D 10:14h	90	>99	0	0
16°C L:D 12:12h	90	>99	died	0
16°C L:D 14:10h	100	92	0	0

### Original isolates

1. Flinders 26.7.77
2. Flinders 26.7.77
3. Flinders 17.9.77
4. San Remo 29.11.75



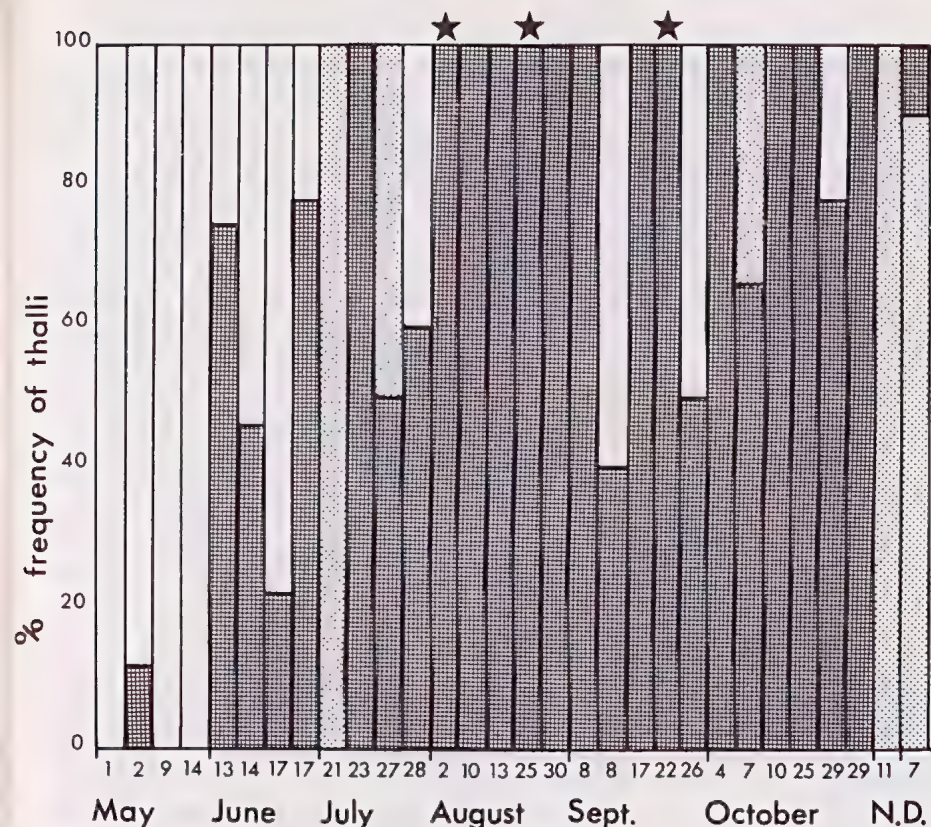


FIG. 2—*Scytosiphon* sp.—seasonal changes in the percentage frequency of wild complanate thalli producing gametophytic and sporophytic (or predominantly sporophytic) progeny. (Occasional cylindrical progeny are indicated by stippled shading. Their occurrence has been discussed in previous publications).

were tested. Cultures were inoculated with three very young gametophytic germlings, 7-14 days old. When sori were observed on the fronds, usually from an age of 6-8 weeks onwards, the culture dish was placed in a black plastic sleeve that masked half the contents. This enabled the phototactic response of the zooids to be determined, after which the sleeve and the parent thalli were removed. The progeny were cultured until it was clear whether they were gametophytes or sporophytes. When both were present the proportions of each were estimated by counting sample fields, or if possible the entire population using a stereo dissecting microscope.

#### GAMETOGENESIS IN CULTURED *SCYTOSIPHON* SP.

Thirteen strains were tested. The culture dishes were inoculated with single gametophytic germlings. They were grown at 14°C, L:D 10:14h, conditions approximating those in which wild *Scytosiphon* sp. produces gametes (Figs 2 & 3). From the time the plants became fertile their zooids were checked at weekly intervals and were matched with zooids from plants of the opposite sex. The presence or absence of mating reactions followed by the formation of zygotes was recorded (Table 2).

## RESULTS

### THE EFFECTS OF TEMPERATURE AND DAYLENGTH ON *C. PEREGRINA*

*C. peregrina* did not reproduce in the same way in all temperature/daylength conditions. Two strains produced a large proportion of sporophytic progeny in all conditions, and the other two did so only in three of the eight sets of conditions (Table 1), indicating that both daylength and temperature affect reproduction.

Subsequently, in conjunction with other studies of the effects of temperature and daylength on life history, five more strains of *C. peregrina* were cultured in four new temperature/daylength regimes (Table 3). The strains were of the kind which produced gametophytic progeny in most conditions. In all the test conditions they continued to produce gametophytes. Although different from the strains used in the first experiment, the results permit further definition of the environmental conditions which limit sporophyte production and the potential for sexual reproduction in *C. peregrina*.

The phototactic responses of *C. peregrina* zooids were in most instances not clear as large numbers of germlings developed in both darkened and light parts of the culture dishes. Under the



TABLE 2  
*SCYTOSIPHON* sp. — THE AGE IN DAYS OF CULTURED GAMETOPHYTES WHEN THEY PRODUCED  
 NON-SEXUAL ZOOIDS AND GAMETES

Cultured strains	Sex	Zoid production			Gamete production	
Flinders 2.8.76	i. F	44	61			
	ii. M	44	61		88	91
Flinders 15.8.78	i. F	78	101		128	132
	ii. M				115	132
	iii. F				132	
Flinders 19.9.78	i. F	60	67	84	98	
	ii.	67				
	iii. F	84			98	
	iv.	84				
	v. F	84			98	
	vi.	60	84			
	vii. F				98	
	viii. M				8	

same conditions *Scytosiphon* sp. zooids show a more definite phototaxy: negatively phototactic zooids develop into sporophytes and positively phototactic zooids develop into gametophytes (Clayton 1980).

#### GAMETOGENESIS IN CULTURED *SCYTOSIPHON* SP.

Four gametophytes produced only non-sexual zooids. Five plants initially released zooids which failed to mate with zooids from plants of the opposite sex, but on later occasions they released functional gametes (Table 2). All the zooids released by the four remaining strains included some gametes. The exact percentages of gametes which were successful in forming zygotes were not calculated but it was clearly only a fairly small proportion of those released.

#### DISCUSSION

The reproductive cycle of *C. peregrina*, like that of *Scytosiphon* sp., is controlled by environmental factors. It is significant that the conditions (12°C, L:D 10:14 and 12:12h, and 14°C L:D 10:14h) which induced sporophyte production in otherwise gametophyte-producing strains of *C. peregrina* correspond to the temperatures and daylengths prevalent in winter in Victoria (Fig. 3), the time of year when wild *C. peregrina* invariably produces mostly sporophytic progeny. The range of daylength in which gametophytes give rise to sporophytes is narrower than it is in *Scytosiphon* sp. (Figs 1 & 2) in which long days also induce sporophyte production. The ephemeral wild

plants show a related difference in their seasonality: *C. peregrina*, although inconspicuous in summer, occurs throughout the year, whereas *Scytosiphon* sp. is absent from the shore between December and April.

The existence of strains of *C. peregrina* and *Scytosiphon* sp. that persistently produce sporophytes irrespective of temperature and daylength and others in which reproduction is affected by environmental conditions, has been discussed previously (Clayton 1979, 1980). The basis for this difference is at present obscure, but it should become apparent from detailed analyses of inheritance and life histories.

Previous research has shown that temperature and daylength may affect the life histories of a number of species in the Scytosiphonaceae in several ways (Wynne & Loiseaux 1976). An association between long days and sporophyte production has been demonstrated in the cylindrical *Scytosiphon lomentaria* (Lyngbye) Link (Wynne 1969; Nakamura & Tatewaki 1975). However, no study has been sufficiently detailed to provide a comprehensive definition of the range of conditions which determine the production of sporophytic and gametophytic progeny in any species.

In several species of the Scytosiphonaceae, gametes have been shown to develop parthenogenetically into sporophytes; a small number of parthenogametophytes occasionally also develop (Nakamura & Tatewaki 1975; Clayton 1979, 1980). In the brown algal species *Ectocarpus siliculosus* (Dillwyn) Lyngbye (Müller 1967), and

in the green alga *Ulva mutabilis* Føyn, (Fjeld & Løvlie 1976), parthenogenesis likewise leads to sporophyte development. The reasons are doubtless complex why many of the zooids from wild and cultured *Scytosiphon* sp. and *C. peregrina* which ultimately develop into sporophytes do not function as gametes, but one factor implicated by the present study of *Scytosiphon* sp. relates to the age of the gametophytes, a phenomenon which has not previously been reported. Unfortunately it is impossible to say whether the impotence of the first-formed zooids of some gametophytes was a character of one or both sexes, as functional male and female gametes were not available simultaneously for the appropriate checks to be made. It is interesting to note that the age of cultured *Scytosiphon* sp. on reaching sexual maturity corresponds approximately to the length of time wild gametophytes are present on the shore before they begin to release gametes in late winter. However, there is no information available on the rate of growth and the longevity of wild plants so this correlation must remain speculative. The subject is currently under investigation.

Even if age is a factor in the development of sexual competence in *Scytosiphon* sp., the fact remains that gametophytes are common on the shore for seven months of the year, they produce sporophytic progeny for the greater part of five months, and yet gamete-producing plants have been recorded during a period of no more than seven weeks in the winter and early spring. The same is also true of *C. peregrina* except that the period of sporophyte production is three months.

TABLE 3

EXPERIMENTAL CONDITIONS USED IN THE SECOND INVESTIGATION OF THE EFFECTS OF TEMPERATURE AND DAYLENGTH ON THE REPRODUCTION OF *COLPOMENIA PEREGRINA*

*Temperature/Daylength*

12°C L:D 10.5:13.5h

14°C L:D 9.5:14.5h

14°C L:D 12.5:11.5h

16°C L:D 10.5:13.5h

*Original isolates*

1.	Point Nepean	14. 6.78
2.	Sorrento	27. 7.78
3.	Flinders	22. 9.78
4.	Sorrento	10.10.78
5.	Flinders	25.10.78

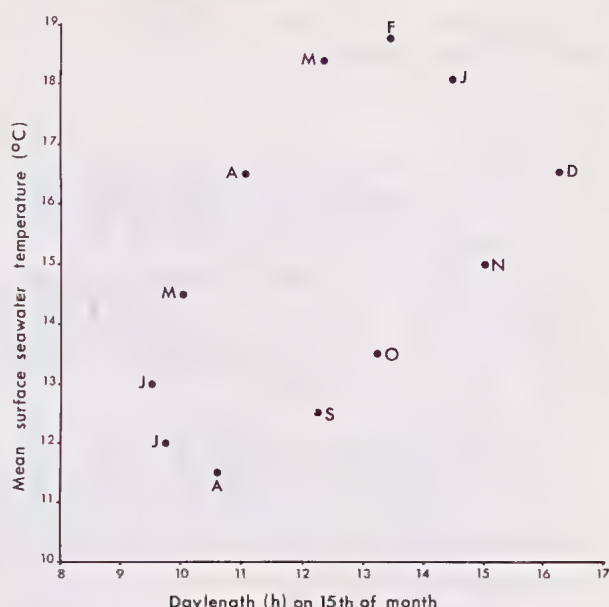


FIG. 3—Daylength and surface seawater temperatures throughout the year in Victoria. (Temperature data obtained from King 1970).

An age-maturity factor alone could not account for the transitory nature of sexuality. The interesting coincidence between the culture conditions in which *Scytosiphon* sp. produced functional gametes (Clayton 1980) and those which induced sporophyte production in *C. peregrina* suggests the possibility that gametogenesis in wild populations may be in some way precisely regulated by changes in environmental parameters such as temperature and daylength.

Many experimental studies of the Scytosiphonaceae have underlined the lack of dependence of the species upon sexual processes as a means of reproduction. For a large part of their growing season *Scytosiphon* sp. and *C. peregrina* reproduce asexually, and even when gametes are produced, many of them fail to form zygotes, but develop parthenogenetically. Furthermore, plants which are able to produce gametes may at some other stage in their development produce non-sexual zooids. It is possible that further studies may reveal selective factors which counterbalance this tendency towards asexual reproduction, as in, for example, *Ulva mutabilis* in which the zygotes have a significantly greater chance of survival than either zoospores or gametes (Løvlie & Bryhni 1978).

#### ACKNOWLEDGEMENTS

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## LATE PLEISTOCENE CHANNELS IN PORT PHILLIP

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**ABSTRACT:** Sub-bottom seismic profiling in Port Phillip has outlined a system of late Pleistocene river channels which now lie buried beneath the bay floor muds in the centre of Port Phillip. These channels are continuations of the present day Yarra and Werribee Rivers, which flowed across the bay floor towards Dromana and Capel Sound during lowered sea levels of the last glaciation. They have cut into a firm substrate of middle Pleistocene clays.

The Yarra Channel begins at Princes Pier where it is 1.5 km wide infilled by 6 m of mud and sand. Down the bay it gradually widens and deepens to 3 km width infilled by 12 m of sediment. It then divides into two branches just north of Mordialloc which in turn subdivide into a series of narrow but deeply infilled distributaries opposite Portarlington.

Four channel infilling seismic sequences are recognised. They comprise two densely layered sequences between which is a non-layered sequence. An overlying non-layered mud layer completes the channel sequence and extends out on to the bay floor. The layered sequences are thought to represent fluvial aggradational deposits whilst the non-layered sequences represent marine deposits. Carbon 14 dates indicate the top mud sequence extends back to 80 000 years BP. The three sequences below remain undated but from sea level curves may include parts of the last glaciation at 18 000 years BP, an interstadial at 80 000 years BP, and an earlier stadial at 90 000 years BP.

### INTRODUCTION

Port Phillip on the southern coastline of Victoria is an almost totally landlocked water body of 1167 km<sup>2</sup> and 24 m depth towards the middle. Sand shoals behind the Nepean Peninsula almost close the southern outlet to Bass Strait except for the deep water tidal entrance known as the Rip (Figs 1, 2).

The Port Phillip sunklands are considered part of the Otway Basin, the development of which began as a rift system on the southern margins of Australia in Early Cretaceous times. The sunkland margins are the subparallel Rowsley and Selwyn Fault Systems between which up to 1000 m of Cretaceous and Tertiary sediments have been deposited.

Around the edges of the bay, outcrops of mainly upper Tertiary and Quaternary sediments and volcanics form steep bluffs and offshore reefs, interspersed with long narrow embayments between Recent beach and dune sands.

Port Phillip floor sediments comprise sands around the periphery which grade with depth into muds in the centre. In the south, deeper water

muds are juxtaposed against the steep northerly slope of the Nepean Bay Bar sand shoals. Sands and muddy sands cover approximately half the bay floor area.

In 1977, the Marine Geology Section of the Geological Survey commenced a study to correlate the known distribution of the surface sediments of Port Phillip with the aid of a sub-bottom seismic profiler, and to provide additional information on the immediate subsurface geology of Port Phillip and its relationships to the outcrop geology on-shore. The results of this survey outlined a system of river channels which now lie buried beneath the bay-floor muds in the centre of Port Phillip (Fig. 2).

Following the sub-bottom seismic survey, targets were selected from the seismic records and were drilled using a vibrocorer to obtain core samples to help identify the main seismic reflectors. The profiling and coring were also designed to assist with interpreting the more detailed coring and sampling programs undertaken by the Ports and Harbours Division around the sand areas of the bay.



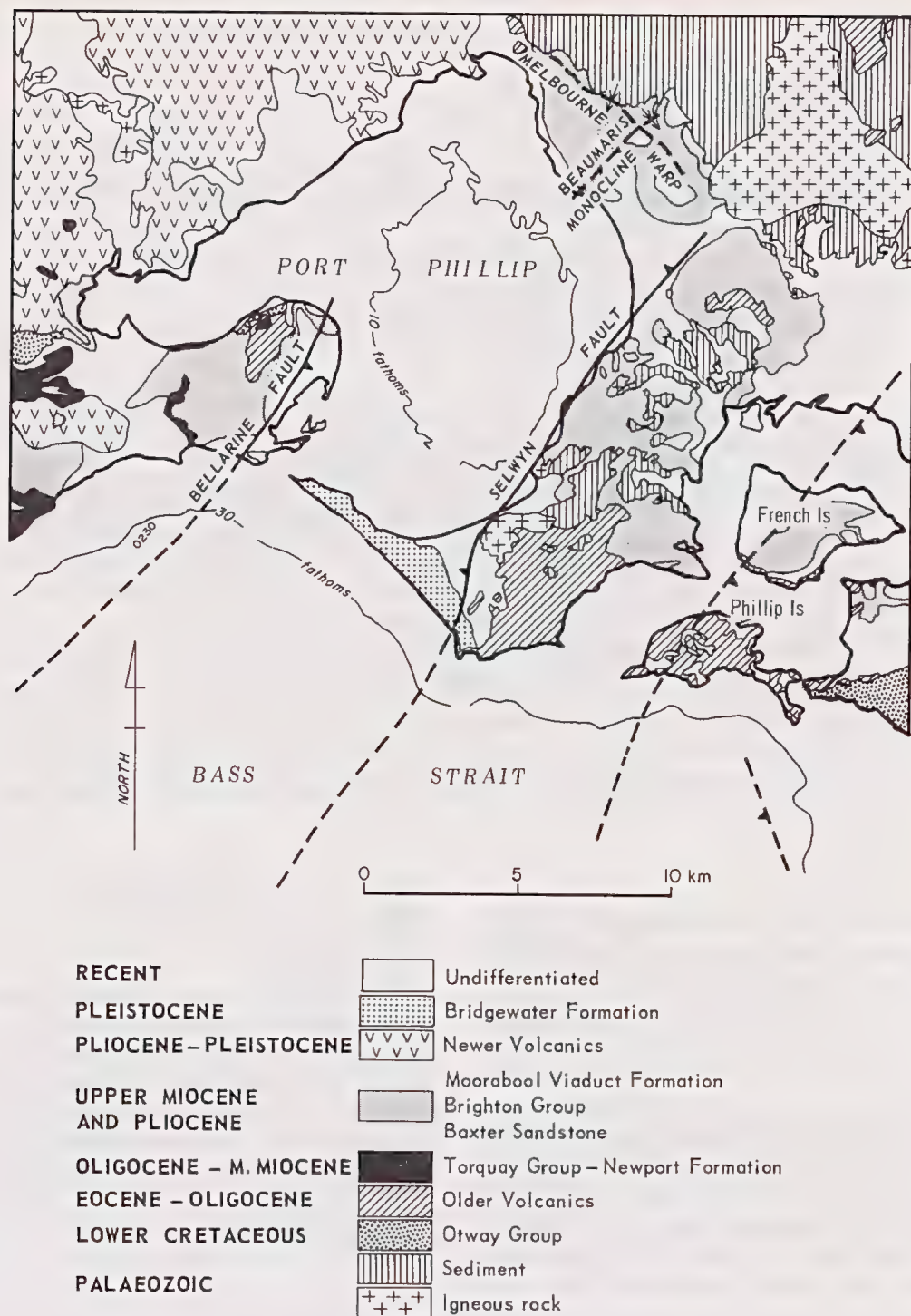


FIG. 1—General geology of Port Phillip.

A summary of previous work investigating the bottom sediments of Port Phillip (Beasley 1966) and results of the 1957-1963 Port Phillip Survey have been published by the National Museum of Victoria. The first comprehensive seismic survey

of Port Phillip was undertaken for ESSO-Australia as part of a study of a submarine pipeline between Mordialloc and Altona. This survey delineated the position of some of the channels described in this paper. Similar seismic

surveys, using a boomer in more localised areas of Port Phillip, have since been made by the Geology Department, Melbourne University (Walsh 1978).

Keble (1946) postulated the existence of an earlier Yarra River course from his study of bathymetry in Port Phillip but this work was later regarded as speculative (Bowler 1966). Keble did not conceive the possibility of a buried channel system as outlined by the sub-bottom profiler but, despite this, the two systems are in general agreement as they both coincide with the deepest parts of Port Phillip.

## METHODS

The survey work launches supplied by Ports and Harbours mostly contained Decca trisponder navigation equipment for accurate co-ordination to within 1 m or less. Some sextant fixes were made in the northern parts of the bay. Boat speeds during seismic surveying varied between 3 and 5 knots in waters not exceeding 1 m wave height.

The sub-bottom seismic profiler manufactured by Ocean Research Equipment Inc. includes a transducer, transceiver, and a graphic recorder. The transducer hung over the side of the boat about 2.4 m below the surface.

Thirty-six seismic runs, totalling 656 km, were made during 1977 and 1978 (Fig. 3). Most runs occur in NE or SW directions, with an average space between runs of 5 km. Seismic penetration to 50 milliseconds 2-way time (approx. 37.0 m) was obtained under ideal conditions such as in soft muds, with resolution of single beds down to 1 millisecond (approx. 0.7 m). In sandy or consolidated bottom areas penetration was ineffective. As most of the study area comprises soft muds overlying consolidated clays, seismic penetration was adequate to discern most of the younger features.

A signal velocity equal to that of sound in water of 1.5 km/sec was assumed for the unconsolidated sub-bottom sediments and this was confirmed later by coring.

The main seismic events were subsequently reduced using a Hewlett-Packard digitiser and X-Y plotter, and corrected for boat speed and drift (see Fig. 4).

The sediments were cored by a compressor driven vibrocorer which was lowered to the sea bed. The core sample was vibrated out of the core tube into a plastic liner. Maximum core length obtained was 4.2 m. Twenty-eight sites were chosen from the sub-bottom profiling results for coring, and from these about 50 m total of core was obtained.

Results of more detailed coring and sampling by Ports and Harbours on the periphery of the bay were also used for correlation purposes. Additional data were obtained from drilling results for ESSO Australia along the line of the ethane pipeline, and from engineering studies along the Port Melbourne Channel (Holdgate 1977).

Radiocarbon dates were obtained from the Sydney University Radiocarbon Laboratory on five samples submitted, and 15 samples were examined for nannofossils.

## RESULTS

The combined drilling and seismic surveys indicated the occurrence of sediments that can be grouped into three distinct stratigraphic units.

### PORT PHILLIP—FLOOR SEDIMENTS

#### 1a Peripheral Sands

These occur around the periphery of Port Phillip and on the Nepean Bay Bar. The Nepean Bar sands up to 6 m thick are dominated by tidal currents and display a typical tidal delta morphology. They overlie mid-Quaternary dune limestones from which they derive much of their sand. Elsewhere in the bay the sand forms are dominantly sculptured by wave action and are comprised of a nearshore sand bar zone up to 3 m thick responsive to seasonal variations in wave regime, and an offshore sand zone usually about 1 m thick of dominantly relict material which grades seawards into sandy muds and muds.

The peripheral sands unconformably overlie basement (Tertiary or Quaternary) from which they derive some of their material, and  $C^{14}$  dating shows they are mainly Holocene in age. Figure 5 shows the Carbon 14 dates of some samples from the base of the peripheral sands, plotted with various smoothed curves of Holocene sea levels. The dates from shells fall below the curves (they were originally deposited below the contemporary sea level) and the dates from basal carbonaceous material plot close to the Holocene sea level curves.

Remnants of a pre-Holocene marine transgression deposit were found at St. Kilda where iron-stained shells (suggesting sub-aerial weathering) at the base of the peripheral sand were dated at  $33\,900 \pm 2\,000$  (SUA 994). Since this date is near the limit of practical  $C^{14}$  detection and contamination by modern carbon is possible, it is taken as a minimum only. The shells lie at about 5 to 6 m below sea level, and so may be as old as 120 000 years, the last interglacial; later interstadials are not thought to have reached this height (Marshall & Thom 1976).



### 1b Central Muds

A layer of soft grey mud with some silt, sand and marine shells occupies the central 500 sq km of Port Phillip and grades marginally into the peripheral sands. The muds thicken towards the middle of the bay and overlie a mid-Quaternary basement of consolidated clays, except in the infilled channels where it overlies additional sediments of Late-Pleistocene age.

The muds are designated as Sequence A of the channel infill sequence and north of seismic run 24, are restricted by basement subcrop to within the filled channels. Their thickness is variable where they infill undulations in the basement surface underneath. They average about 4.4 m thick. Outside the infilled channels the muds are usually very shelly at the base. Similar muds occur in the Outer Harbour—Corio Bay area near Geelong.

Nannofossil studies by R. Wilks (pers. comm.) indicate the central muds are of the youngest Quaternary zone and, from their content of molluscan fossils, are thought to be entirely Holocene in age. These sediments are discussed in more detail by Holdgate *et al.* (in press).

### 2 CONSOLIDATED SEDIMENTS

The consolidated sediments on which the basement surface is formed are thought to be mainly Tertiary around the edges of Port Phillip (similar to the coastal cliff exposures), and Quaternary in the centre as occurs in the Yarra Delta (Neilson 1976). The relationship between the two is not apparent because sand surface sediments mask their junction but it is thought that Quaternary basement units onlap the Tertiary units in this area. Walsh (1978) reports boomer seismic evidence of post-Tertiary units that predate the channel infilled sequences and onlap the Tertiary.

The basement is not generally penetrated by the seismic frequencies used and, on the profiles, the surface appears as one of undulating erosion. In coring basement, penetration was limited and was generally a stiff clay, mottled and leached in appearance—sometimes with small root fragments. These clays were unfossiliferous but, in the middle of the bay, appear to be similar lithologically to the mid-Pleistocene aged Fishermens Bend Silt (Neilson 1976). On the edges of the eastern side of the bay the cores of basement are lithologically similar to the late-Tertiary sandy clays and sandstones of the cliff exposures.

Mid-Quaternary aeolianites underlie the sands of the Nepean Bay Bar, and eroded Quaternary basalts were also cored on the west side of the bay near Altona.

In relation to the surface marine sediments and the infilled channel sediments, these Quaternary and Tertiary aged consolidated rocks make up the same geomorphic unit, described in this paper as the basement surface. They form the "acoustic basement" on the seismic profiles produced by the ORE acoustic profiling equipment and are referred to as such elsewhere in this report.

### 3 INFILLED CHANNELS

A sediment infilled channel system down the centre of Port Phillip marks the ancestral course of the Yarra River developed during past glacial periods of low sea level. These channels contain three seismic units which are not recognised elsewhere in the bay.

In broad outline (see Fig. 4) the infilled channel system has been traced from offshore in Hobson's Bay at Princes Pier as a single channel 1.5 km wide and with a maximum thickness of 8 milliseconds (5.8 m). Channel floor irregularities and protuberances indicate the valley floor was cut by a number of shifting and meandering stream or river patterns which left isolated ridges in the sub-channel clays. Valley sides on the profiles appear almost vertical in places but when recorrected for vertical exaggeration do not usually exceed more than 10°, and most slopes are probably less than 5°. From Princes Pier the Yarra Channel swings SSW across Hobsons Bay to pass immediately off the end of Gellibrand Pier (Williamstown) south of which it is joined by a second channel from Kororoit Creek. The main channel can then be followed southwards gradually widening and deepening so that on the Sandringham latitude (run 25) it has become 3 km wide and 17 milliseconds (12.4 m) deep. Shortly south of run 25 it splits into two branches of approximately equal width separated by an inter-channel "basement" high as shown in run 24. This splitting also coincides with the spoil ground dumping area, the spoil from which has prevented effective sub-bottom penetration in places, but by run 17 which is past the spoil ground area the between-channel basement high is clearly defined. Sediments in the eastern channel are nearly twice as thick as in the western channel; the latter coincides with the deepest part of the bay floor. This double system continues to the latitude of Carrum at run 19 where both branches bifurcate into a number of narrow but deeply entrenched channel sub-branches with up to 38 milliseconds (27.7 m) of fill. At about this point they are joined by an infilled channel which trends SE across Port Phillip

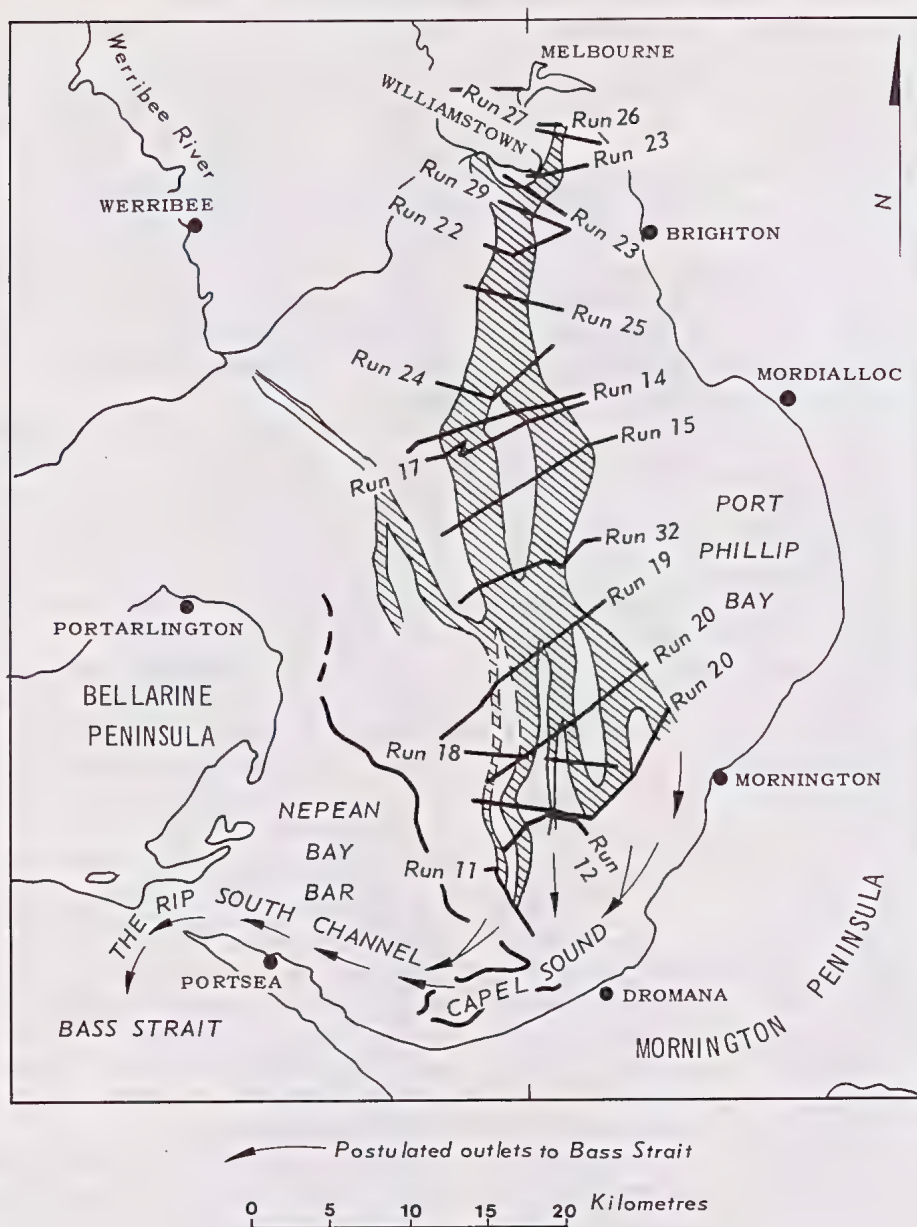


FIG. 2—The late Pleistocene channel system.

from the mouth of the Werribee River. For convenience the western channel branch and its northern extension into Princes Pier will be referred to as the Yarra Channel, and the deeper eastern channel branch and its distributaries to the south are referred to as the Prior Yarra Channel.

As the Prior Yarra distributaries approach the coastline between Mornington and Dromana they are progressively lost on the sub-bottom profile record as they traverse beneath the sandy sediments peripheral to the coastline. The Yarra Channel can be followed the furthest underlying

the deepest part of Port Phillip to reach a 27 m sea floor depression immediately north of the Middle Ground sand bank. Further south all the channels are lost beneath the sand banks of the Nepean Bay Bar, but evidence is presented in the discussion to show they all may have joined up in the Capel Sound area and then passed out into Bass Strait via South Channel and the Rip.

The stratigraphy of the channel infilling sequence has been determined mainly from the sub-bottom profiler, as most of the three lower sequences are too deep to be reached by conven-



tional vibrocore techniques. The correlation of the four main sequences in the centre of the channel down Port Phillip is shown on the cross section Fig. 6—these will be referred to from the top as Sequences A, B, C, and D.

The top sequence (the central muds) is the best understood and is the same as the sea-bottom muds elsewhere in the central part of the bay. It has been cored to maximum 6.05 metres (Esso core No. 3, 3 km south of Williamstown). Acoustically it appears to be a homogeneous unit with few if any strong reflective surfaces. Minor lithological differences noted in some of the cores from this interval may be responsible for the faint banding seen in places on the seismic profiles. It appears to overlies conformably the next sequence down and although it is thicker in the channels it is the only one of the four sequences which occurs outside the main channel areas (Fig. 4).

Below this topmost mud layer and occurring only within the channels is a densely layered sequence exhibiting in places inclined bedding, which thickens and dips down from the channel sides towards the channel bottoms. Beds down to the limits of seismic resolution (0.7 m) are distinguishable and in places drape the sides and across the tops of the mid-channel irregularities. In the Yarra Channel sequence B forms the base of the sequence and at least two cores probably reached this level—Esso core No. 3 drilled towards the edges of the channel 3 kilometres south of Williamstown and contained 2 m of fine quartz sands (sequence B) below 2 m of mud (sequence A); and Australian Dredging core No. 1 off Point Gellibrand contained 0.3 m of grey slightly clayey medium to coarse sand (sequence B) below 2.1 m of brown sandy clayey silt (sequence A).

Where the channel branches into two, south of run 25, the layered strata of sequences B can be followed from the base of the Yarra Channel discontinuously across local hollows in the inter-channel basement high to lie across the middle of the infilling sequence in the Prior Yarra Channel, thus forming a contemporaneous marker event across the whole channel system and indicating a previous episode of cut and fill in the Prior Yarra Channel.

It is assumed that the layering within sequence B was produced by a predominant sandy sequence with interbeds of silts and muds. Towards the centre of the Yarra Channel sequence B is about 8 milliseconds (5.8 m) thick and maintains this thickness down the whole channel. On many of the seismic profiles sequence B sediments cause a masking effect below the channel base, which is a

similar effect to that produced below a sandy or gravelly sea floor.

Sequence C first appears clearly on Run 24 and after this is confined to the Prior Yarra Channel and its distributaries. This is acoustically transparent and non-layered, and is up to 12 milliseconds (8.7 m) thick. It is seismically identical to the central muds (sequence A). In more southerly runs it appears to include some fine layering. It is not recognised in the Yarra Channel except perhaps on Run 25, and its appearance therefore broadly coincides with the first channel bifurcation.

Sequence C fills in and abutts against the channel sides and drapes over the mid-channel basement irregularities; it has been cut into in turn by the overlying Sequence B. It may originally have extended beyond the channel confines but was removed elsewhere by erosion. The reduced level on top of Sequence C is at no time less than -22 m below present sea level.

Sequence D occurs below sequence C from run 24 south only in the Prior Yarra Channel and like sequence B is strongly laminated and cross-bedded, with beds dipping from the channel sides towards the channel bottoms. On most traverses it is confined to the deeper bases of the channel and its distributaries except on runs 15, 17, and 32 where it has veneered the western channel walls and here is unconformable with sequence C. The seismic record indicates a similar layering of sands, silts, and lesser muds as in sequence B, and on some runs produces masking effects on the profiles indicative of a sandy or gravelly nature. It overlies unconformably what appears to be the same clay basement formation as is present outside the channel areas.

South of Run 24 the base-of-channel slope changes from 1 in 1000 to 1 in 2500, which position also approximates with the splitting of the channels. This suggests that a decrease in slope of the former land surface caused a drop in stream velocities which may be the reason for the change from a single wide braided river valley in the north to a series of narrow meandering valleys in the south. Where all signs of the channels are lost near the Nepean Bay Bar, the channel bases have been cut to a maximum of 66 milliseconds (48 m) below present sea level.

## DISCUSSION

### 1 AGE OF THE CHANNEL INFILL SEQUENCES

Lacking confirmatory core data, certain assumptions have been made about the en-

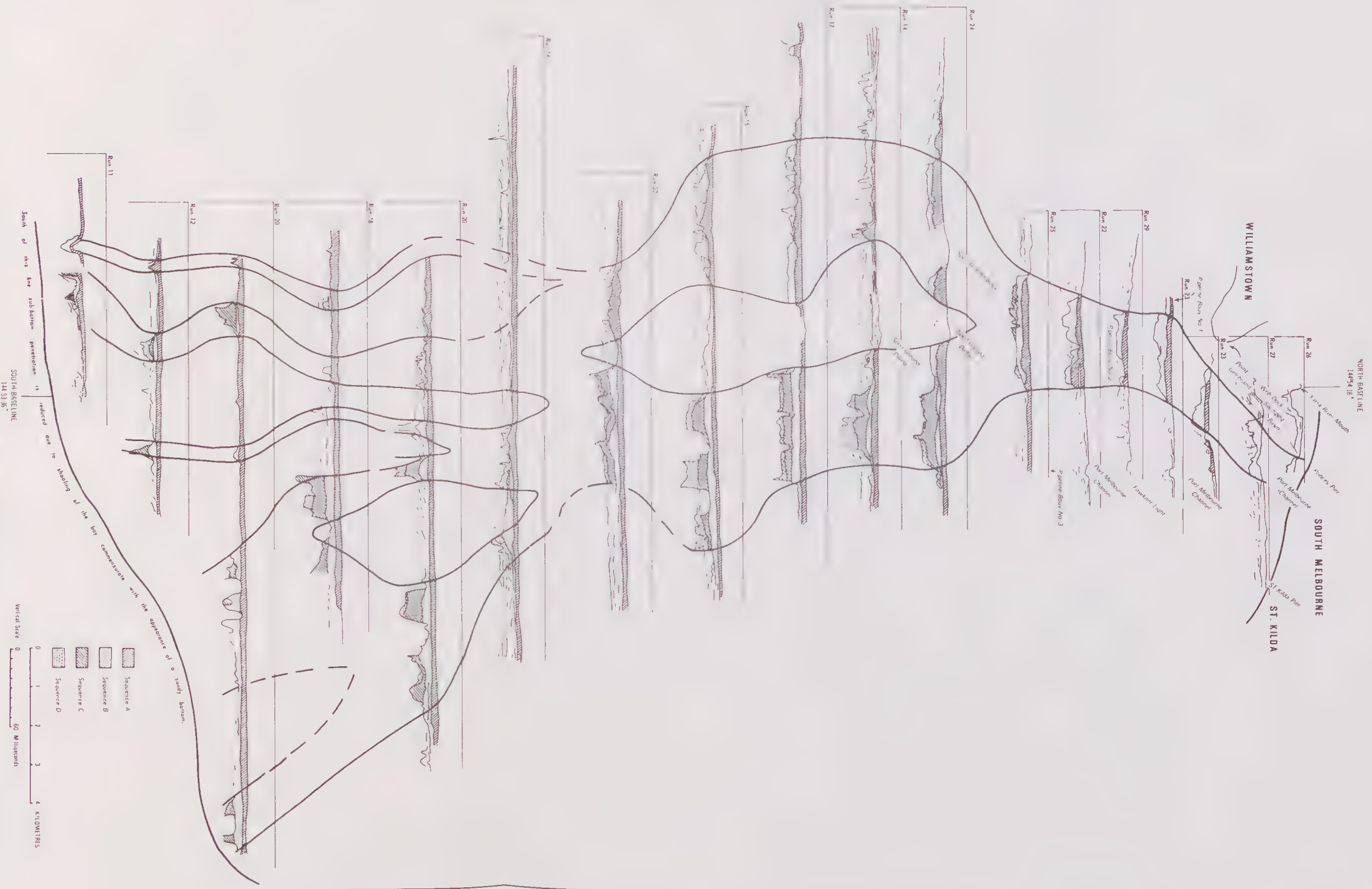


Fig. 4—Stylistic presentation of the late Pleistocene infilled channel systems in Port Phillip.





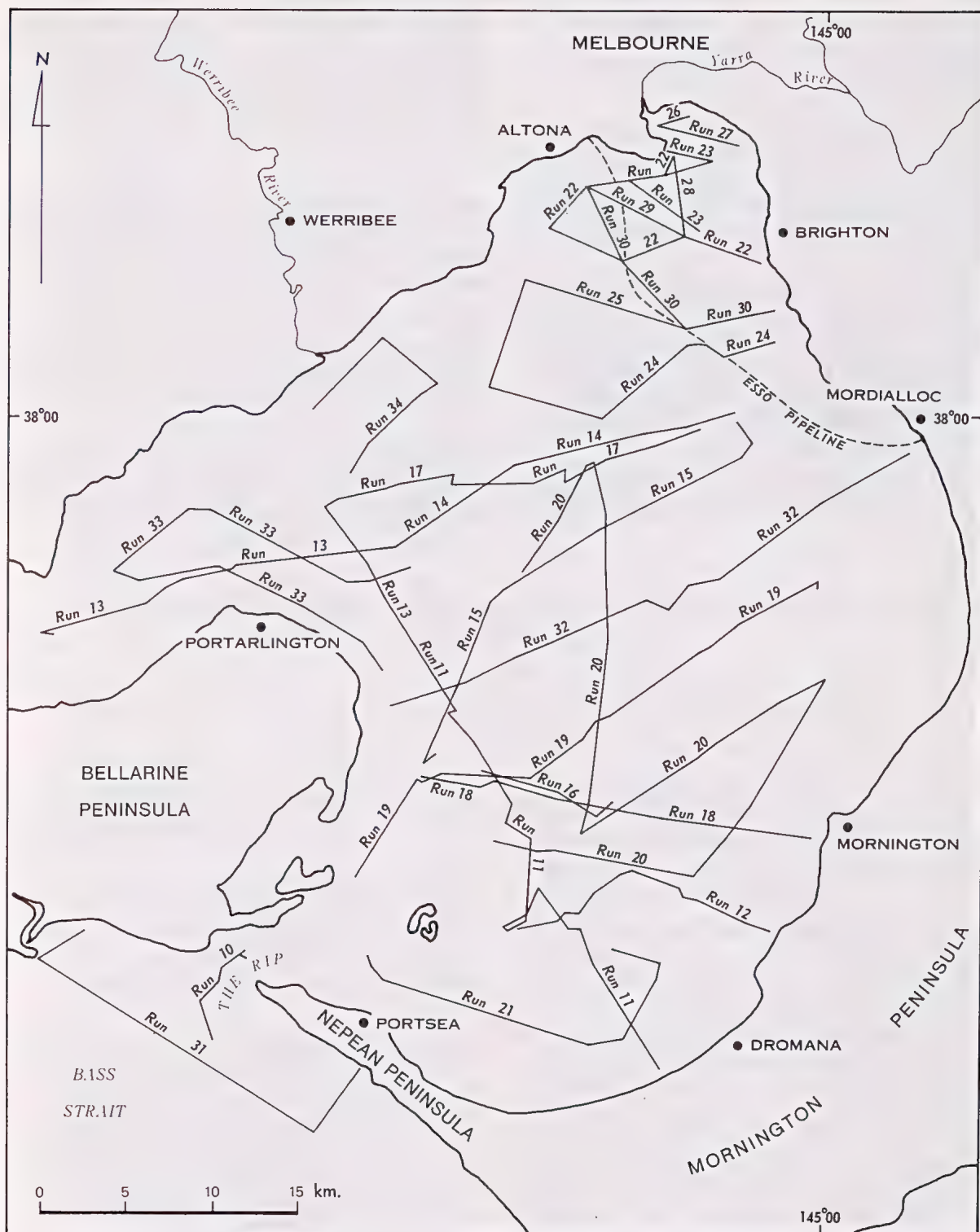


FIG. 3—Locality diagram of sub-bottom runs in Port Phillip.



vironments of deposition of the channel infill sequences based mainly upon their seismic appearances which are more fully detailed in the previous section. These are:

(i) the non-layered Sequence C is similar to Sequence A which is predominantly a marine mud sequence, and therefore both A and C represent depositional periods of marine transgression during rising, and for A, currently stabilised sea levels.

(ii) the layered Sequences B and D from their geomorphic position, stratification and boundary contacts are essentially non-marine fluvial aggradation sandy phases which accompanied or followed soon after the periods of channel cutting, and hence represent periods of regression during glacial stages of falling sea levels.

(iii) from the above it is recognized that the infill sequences of the Yarra Channel represent a single

cycle of events beginning with channel cutting, fluvial aggradation, and then later marine infilling. On the other hand the Prior Yarra channels south of Run 25 include this cycle which is superimposed upon an earlier cycle which had followed a similar sequence of events.

If the highest and lowest points of the 4 stratigraphic sequences are plotted as a longitudinal section (Fig. 6) the following events from oldest to youngest, took place to bring about the channel sequence in Port Phillip.

(i) sea level fell to -48 m or lower—down cutting of rivers into an older and weathered land surface of the Fishermens Bend Silt and Tertiary formations. This downcutting tended to favour the more easterly channel (Prior Yarra) sites.

(ii) aggradation commenced in the channels, depositing *Sequence D* south of Run 25. Either no aggradation occurred north of Run 25 or else the

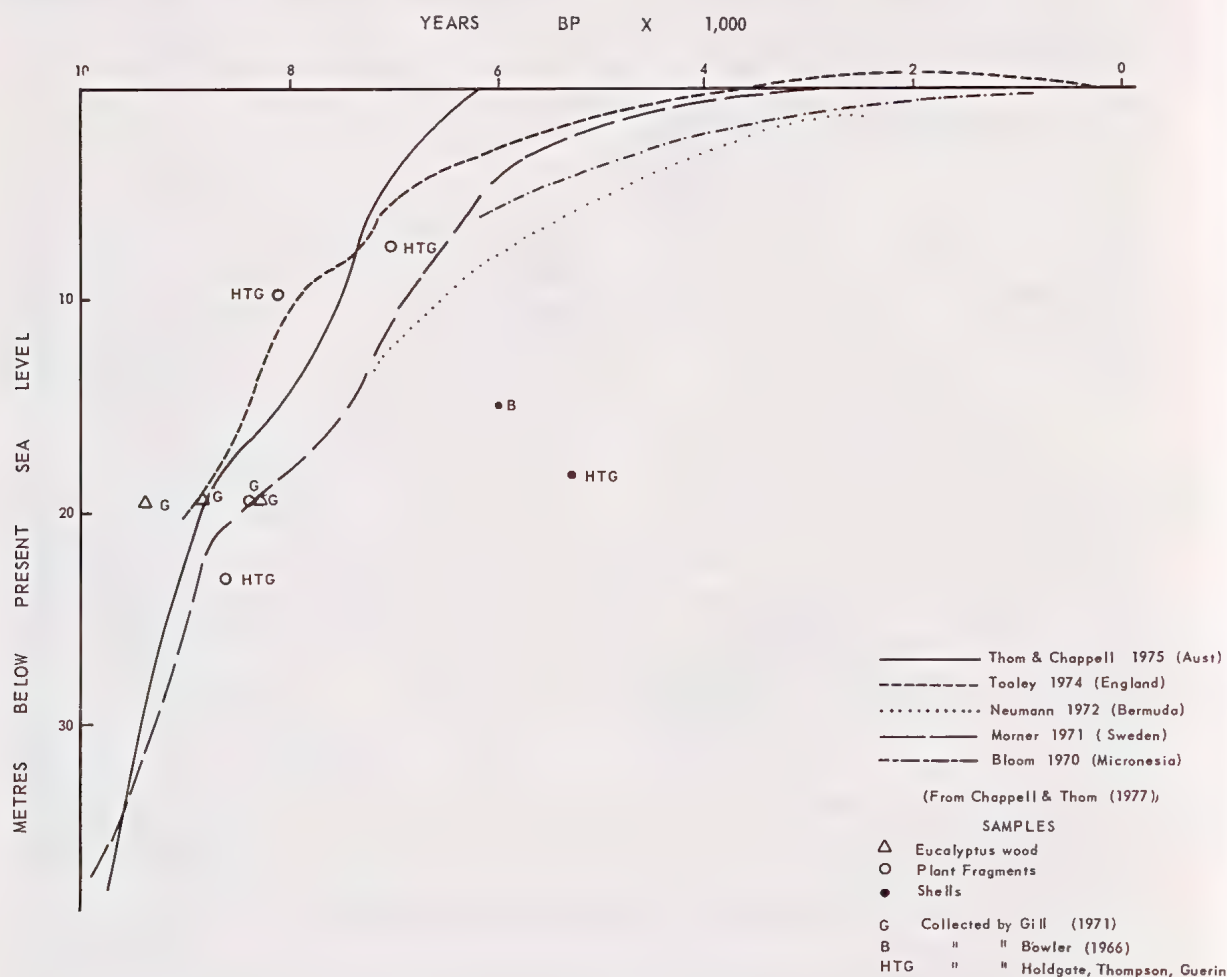


FIG. 5—Carbon 14 dates in Port Phillip compared with world sea level curves.





BP), or a younger interstadial transgression such as the  $-18$  m palaeosea level recorded by Chappell (1976) and Chappell & Thom (1978), dated at about 80 000 years BP. Certainly if it was not later removed by erosion, the fact that Sequence C (Stage iii) is not found above  $-22$  m would suggest that sea levels at the time may not have risen as high as at present, whereas the sea levels during the last interglacial stage are generally thought to have exceeded present sea levels (Marshall & Thom 1976). Stages (i) and (ii) (sea level below  $-48$  m, channel cutting then infilling) could therefore represent the earlier part of the last glaciation, say a low sea level stadial before 80 000 years BP but younger than 120 000 years BP instead of being events of the penultimate glaciation of pre-140 000 years BP (Fig. 7).

Either alternative lies well within the absolute maximum age for the channelling events obtained from the 0.81 million year date on the Burnley Basalt in the Yarra Delta which interbeds and underlies the Fishermens Bend Silt (Page 1968)—the latter being considered as basement underlying the central muds and the infilled channel sequences.

## 2 CHANNEL PATHWAYS TO BASS STRAIT

Evidence for lower sea levels down to  $-120$  m during the last glaciation have been documented on the Australian continental shelves (e.g. Jones 1973) and substantiated in other parts of the world. It could be expected that the channel features formed in Port Phillip at this time would have exited to Bass Strait through the Nepean Bay Bar. Unfortunately the sand shoals of the bar exclude the possibilities of tracing such features with the sub-bottom profiler because of its limited penetration in these sediments, and similarly runs made immediately outside Port Phillip Heads in Bass Strait (Runs 10 and 31) show a similar reflective sandy bottom. Sparker seismic and sampling by the Bureau of Mineral Resources showed sandy sediments form a veneer over much of the continental shelf south from the Nepean Peninsula (Davies & Marshall 1973). No obvious channel-like features were discerned on any of these profiles.

Keble (1946) used the bathymetric contours in Bass Strait to reconstruct a channel course to cut through the Nepean Bay Bar to Bass Strait at around Sorrento. However, this course is not likely for the following reasons:

(i) the channels all head south towards Capel Sound and Dromana rather than towards Sorrento.

(ii) contouring with more detailed bathymetric soundings by Jennings (1959) indicated little evidence for a channel course in this area of Bass Strait.

(iii) so-called fluvial sediments obtained in bores on the Nepean Peninsula come from a stratigraphic interval now recognised as being Pliocene in age (Holdgate 1976).

(iv) recent bores drilled by the Geological Survey between Rosebud and Sorrento show no evidence of fluvial channels through to Bass Strait. In fact all the bores indicate that the whole Nepean Peninsula has been formed by a series of Pleistocene calcareous dunes (aeolianites) which occur down to  $-67$  m below sea level (not  $-130$  m as reported (Chapman 1928), and often quoted since). These rest upon a Pliocene and older

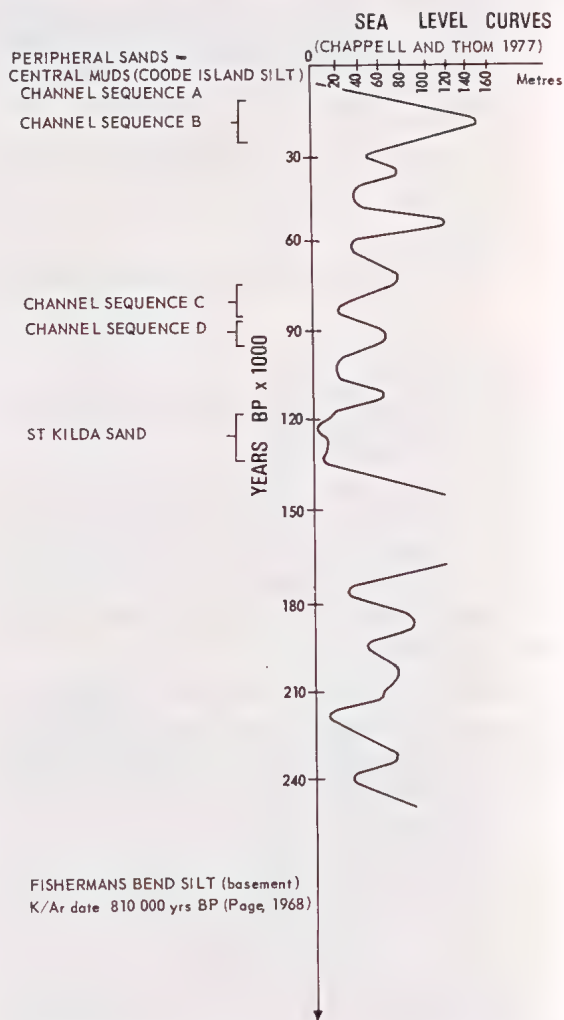


FIG. 7—Stratigraphic units in Port Phillip compared with world sea level curves.

marine calcarenite sequence which extends out into Bass Strait (Holdgate 1976). Similar aeolianite has been reached in shallow bores across the Nepean Bay Bar (Kebble 1946, Guerin pers. comm.) and most likely underlies the whole of the sand shoal areas in the south of Port Phillip.

It is evident from the profiling and drilling that the central muds abutt sharply against the steep north facing edges of the Nepean Bay Bar, and that the aeolianites of this bar which extend to -67 m are all older than the channel features. Therefore it is proposed that the South Channel was a pathway for late Pleistocene river channels to reach Bass Strait via the Rip, which later has been partially infilled by sands during the Holocene transgression. If this is so then below the South Channel, whose sea floor varies between about -11 and -22 m below sea level, the aeolianite bedrock should occur at a level between that of the base of the Rip at -60 m and the base of the infilled channels immediately north of Capel Sound at -48 m.

The Prior Yarra Channels in excavating behind the Nepean Peninsula trended WNW between dune masses of Nepean Peninsula and Middle Ground-Mud Island which have aeolianite at shallow depths. This has also occurred in present day streams such as the Glenelg and the Hopkins Rivers. Unfortunately the data showed no evidence of the Yarra River valley on the continental shelf of Bass Strait such as has been documented for the Glenelg River (Boutakoff 1963), but this is undoubtedly due to the highly reflective nature of the sediments veneering the floor of Bass Strait which would have infilled and smoothed over any such river courses.

## CONCLUSIONS

From the result of a sub-bottom seismic profiling programme, a system of infilled channels underlying the bay-floor muds has been established, trending down the centre of Port Phillip from Hobsons Bay to end near Capel Sound.

The infilling sequences consist of four main layers in the more easterly channel branches, while only the upper two layers are represented in the more westerly branches. The latter are thought to represent a younger channel sequence—the Yarra Channel, formed by a single cycle of late last-glaciation events, consisting of glacially induced fluvial downcutting and aggradation, followed by Holocene infilling by marine muds.

The more easterly channels are thicker and have

cut deeper, and represent a dual cyclic sequence comprising the results of an early last-glaciation period of downcutting and mid last-glaciation marine infilling overlain by the late last-glaciation cycle of events as recorded in the Yarra Channel Branches to the west.

The Yarra and Prior Yarra Channel systems are incised into probable mid-Pleistocene clays which infill the centre of Port Phillip. They are both lost on the sub-bottom profiler beneath Holocene sands of the Nepean Bay Bar. From their lithology and stratigraphic position they probably post-date the Nepean aeolianite which subcrops beneath the Nepean Bay Bar, and they have cut through this to reach Bass Strait via South Channel and the Rip.

Sea level curves (Chappell 1976, Chappell & Thom 1977) suggest the earliest fluvial downcutting events may have occurred during a low sea level stadial at about 90 000 years BP, the intermediate channel infilling occurred during an interstadial transgression at about 80 000 years BP, and the youngest channel cutting occurred during the peak of the last stadial at around 20 000 years BP. The final infilling and smoothing-over process by the bay-floor muds has been Carbon 14 dated, and occurred during the Holocene transgression since 8000 years BP.

## ACKNOWLEDGEMENTS

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## TIDAL SCOUR IN THE GIPPSLAND LAKES

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**ABSTRACT:** The present Gippsland Lakes system formed as sea level rose during the Holocene, and since then has been a depositional basin of very fine grained organic rich sediments. Opening of the artificial entrance in 1889 has subjected the Lakes to greater tidal influence, and as a result many physiographical changes have occurred. One feature of major significance is the extent of tidal scour. Deepening due to erosion averages 3 m in Reeves Channel, reaching a maximum of 9 m in the narrowest section at Metung. Detectable scour has occurred as far west as Point Turner in Lake Victoria. The extent of scour has been determined by comparison of a survey compiled in 1895 and soundings done in September 1979.

Current and salinity measurements within the scour channels show significant stratification, and results indicate that the erosion is occurring during flood tide by the action of high salinity bottom currents. The less dense lake water transports eroded sediment seaward in a surface current during ebb tide. In Reeves Channel flood tide currents of 50-100 cm/sec are transporting coarse sediment into the Lakes in the form of sand waves. Currents capable of erosion (10-15 cm/sec) were recorded in the tidal channel developing south of Raymond Island. The salinity of the Lakes is believed to be increasing due to the continued deepening of Reeves Channel. Therefore the sedimentary regime of the Lakes has changed from a depositional basin, a concept accepted at present, to a dynamic estuarine environment.

### INTRODUCTION

The complex of islands, peninsulas and submerged banks which comprise the Gippsland Lakes system result from the partial drowning of an original coastal plain topography. Successive transgressions into the Gippsland Basin since the late Tertiary produced the sequence of sand barriers; Bird (1965) has identified these land forms as remnants of two prior phases of barrier formation lying behind an outer barrier formed during the Recent transgression of the sea. Evolution of the outer barrier formed this vast sheltered expanse of water.

The fine sediment of the lake bottom reflects the low energy environment in which they have been deposited. An average of 10 m of sediment has accumulated since their formation and cores taken within Lake King and Lake Victoria show the sediment to be 5-30% organic, 10-30% carbonate and the complement to be clay and silt deposited from the rivers. Marine fauna within the sub-surface samples testify to the fact that the Lakes have

always been connected to the sea, at least by an intermittent entrance as described by Rawlinson and others (Fryer 1973).

The opening of the artificial entrance in June 1889 made a permanent connection with the sea and subjected the Lakes to greater tidal influence. The most immediate effect must have been an increase in salinity followed by major ecological changes. Documentary evidence of the ecology before 1889 is not detailed and only major biological changes have been noted since. The bathymetry of the Lakes however, was surveyed in detail between 1892 and 1895, no doubt in anticipation of increased shipping trade passing through the Lakes.

The purpose of the present study has been to determine the nature of any changes in the bathymetry since 1889 and to assess the implications of these changes. The area studied included both Lake King and eastern Lake Victoria as both of the Lakes are subject to tidal effects to some extent. Thus any remarks referring to the 'Lakes' in this paper exclude Lake Wellington.



## METHOD

Initial work involved a series of sounding traverses spaced between 200 and 500 m apart, to establish the extent and form of any depth changes since the 1895 survey. Positioning of starting and finishing points of each traverse were established using colour aerial photographs, giving an estimated error of up to 20 m. The depths were recorded on a strip chart by a Furuno depth sounder. The profile obtained was then digitized and a printout produced of the computed depths and corresponding Australian Military Grid co-ordinates across each traverse. The depths were then plotted on an overlay at the same scale as the original Gippsland Lakes Survey.

The original survey by J. B. Mason was compiled between 1892 and 1895, several years after the entrance had been opened. Mason's charts were mapped on a 1:4800 scale from Lakes Entrance to Metung with an average line spacing of 50 m, and a 1:7200 scale for the rest of Lakes King and Victoria with an average line spacing of 100 m. The results of the original survey are believed to be of a high standard. However, the exact datum could not be established (pers. comm. Chief Hydrographic Surveyor, Public Works

Department). All depths were measured relative to the level of Low Water Ordinary Spring Tide as were the present results, so the datums would be essentially the same. This fact is reinforced by the results of long traverses across uneroded areas of Lake King which agreed consistently with the original survey. In view of the limited accuracy of the present study and the possibility of slight differences in the datums, depth differences of less than 30 cm were not recorded. It should be noted that during normal river flow and calm weather, changes in water level west of Metung are less than 10 cm.

Current readings were taken to determine the area showing a current pattern dominantly attributable to tidal fluctuations. An ebb-flood current cycle was still distinguishable as far west as Point Turner in Lake Victoria, and on this basis two stations were established to study the pattern of current flow in the areas of greatest deepening. The two stations established were in the deepest sections off Metung Peninsula and Harrington Point.

An Endeco current meter was used to monitor current speed, direction and depth over a 12 hour period at each station. To supplement the current

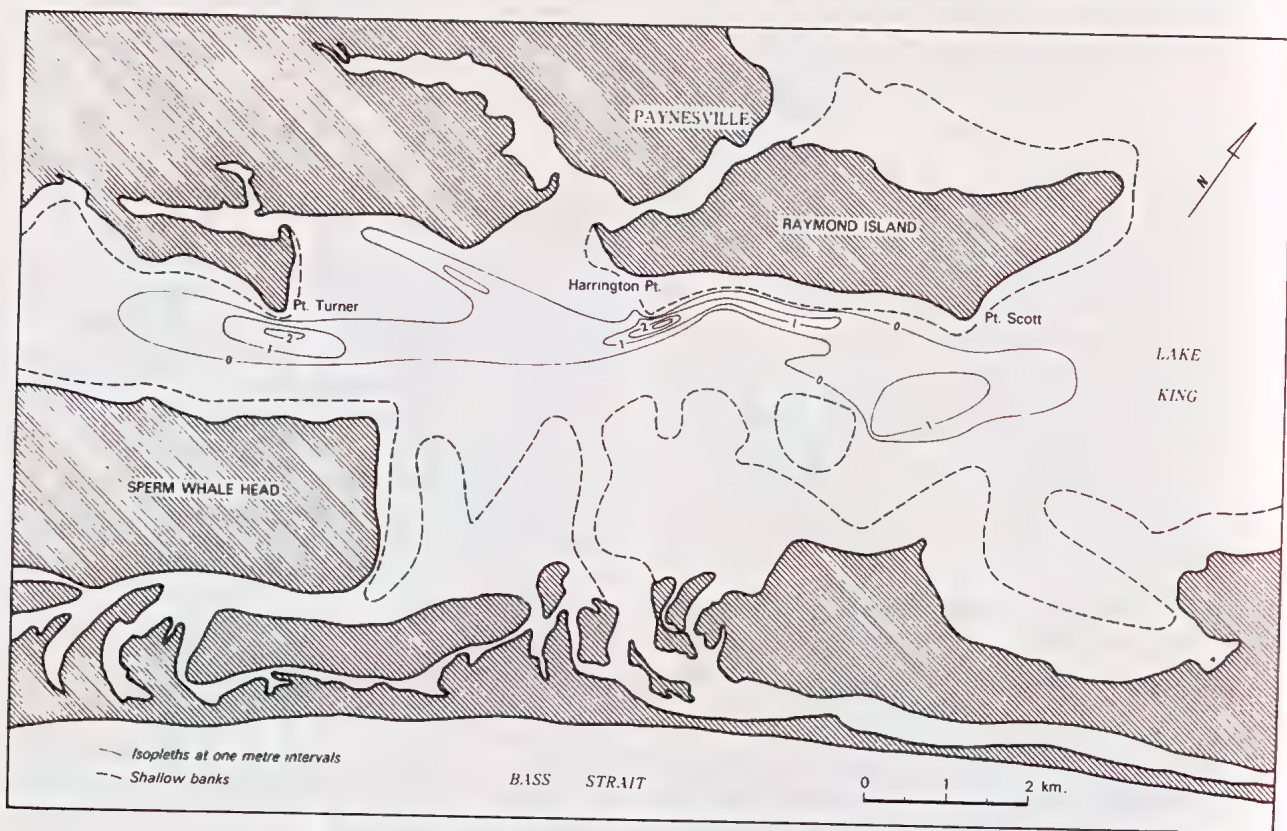


FIG. 1—Isoallo bath map of southwestern part of Lake King.





FIG. 2—Isoallo bath map of eastern part of Lake King to Reeves Channel.

data, readings of salinity, temperature and turbidity, were taken at regular intervals during the tidal cycle.

## RESULTS

In order to assess the significance of the changes in bottom form between the present survey and that of Mason, two isoallo bath maps (Figures 1 and 2) were drawn for the period 1895 to 1979. These were prepared by super-imposing the results of the two surveys and plotting the points of negative or positive depth change. Isoleths were then drawn in relation to these points to establish the configuration of the depth change. The pattern that emerges is a channel system scoured deep into the Lake's sediment. The depth of scour averages 3 m in Reeves Channel but reaches a maximum of 9 m in the narrowest section at Metung. This amounts to the erosion of an estimated  $5 \times 10^6 \text{ m}^3$  of sediment over an area of  $11 \text{ km}^2$ .

The scour channel is not detectable west of Tambo Bluff in Lake King until it begins again south of Raymond Island, continuing west past Point Turner. In this section an estimated  $2.5 \times 10^6 \text{ m}^3$  of sediment has been eroded from an area of  $8 \text{ km}^2$ .

Current measurements within the scour channels showed two distinct patterns of flow, attributable to ebb and flood tide. The ebb flow was dominantly a flow of the upper lake water of lower salinity. The flood flow however entered the system as a dense saline wedge creating bottom currents well into the Lakes system. The bottom currents conform with the shape of the scour channel, while the currents shallower in the profile may vary in direction. Currents measured in uppermost water layers were quite often directly attributable to movement by the wind.

## DISCUSSION

The intrusion of the sea into the Lakes began with the unexpected breakthrough by storm waves in June 1889. This completed the artificial cut in the barrier that had begun nearly 20 years prior. Tidal currents quickly scoured the entrance to a navigable depth and Reeves Channel became a tidal channel through which ebb and flood currents moved in response to the tidal level at the entrance. The 12 km meandering passage into the main body of the Lakes was a significant constriction to the tidal flow and tidal levels in Lake King were greatly diminished relative to the entrance.



Due to the extensive area of the Lakes tidally affected, the volume flowing through the entrance created currents strong enough to maintain a navigable entrance as hoped. The subsequent formation of an offshore bar has been a major restriction to shipping and was the subject of an investigation by the Public Works Department (Fryer 1973).

## EROSION

Bottom sediment of the Lakes for the major part has a mean size of less than 7 microns and a biogenic content up to 50% (Davies *et al.* 1977). Sub-surface samples throughout Lake King show the sediment to be predominantly clayey-silt with a water content of 60 to 70% (King 1980b). In the uneroded areas water content in the upper 0.5 m exceeds 70% (Table 1). Due to the fine grain size and lack of consolidation, the sediment is vulnerable to erosion by current velocities as low as 10-15 cm/sec (Young & Southard 1978). Currents produced by the intruding saline wedge range in velocity from 10 cm/sec to 100 cm/sec, and are therefore capable of causing erosion. The rate of erosion is proportional to the shear velocity and the type of material exposed on the bed. Systematic bottom sampling of the scour channels was not carried out, but two bottom samples taken in the deepest sections at Bell Point and Metung indicate that the sediment being eroded at present is clayey-silt (Table 2) consistent with the composition of the sub-surface samples taken in Lake King.

Scour is continuing despite the recorded increase in sediment consolidation with depth. This is believed to be due to the activity of both benthic

TABLE 1

RESULTS OF ANALYSES DONE ON A CORE TAKEN IN LAKE KING, APPROXIMATELY 1 KM EAST OF POINT FULLARTON

Depth (cm)	Silt content (Wt %)	Clay content (Wt %)	Mean size (Microns)	Car- bonate content (Wt %)	Organic content (Wt %)	Water content (Wt %)
0- 10	66	34	6.5	17	20	73
30- 35	73	27	10.5	20	23	70
60- 65	84	16	13.6	21	15	69
90- 95	84	16	10.3	21	29	68
120-125	98	2	16.6	17	5	68
150-155	78	22	10.5	12	2	67
180-185	64	36	10.6	13	31	67
200-205	78	22	12.0	13	17	67

TABLE 2

RESULTS OF ANALYSES ON TWO BOTTOM SAMPLES TAKEN IN THE SCOUR CHANNEL OFF BELL POINT AND SHAVING POINT, METUNG

Sample Position	Sand con- tent (Wt %)	Silt con- tent (Wt %)	Clay con- tent (Wt %)	Car- bonate con- tent (Wt %)	Or- ganic con- tent (Wt %)
Bell Point	12	44	44	25	38
Shaving Point	21	27	51	30	28

microfauna and macrofauna (Saila 1976). Inspection of the bottom while diving in the scour channels indicates that the upper 5-10 cm is kept in a relatively homogeneous and unconsolidated state due to bioturbation.

In terms of the salinity pattern, the Lakes can be classified as a mixed estuary (Drake 1976) i.e. a nett landward flow of saline water and a seaward flow of less saline lake water. The degree of saline intrusion is determined by the fresh water head relative to the tidal strength. In periods of exceptionally high river discharge there is no intrusion of saline water. Conversely, during periods of low river flow when evaporation exceeds fresh water inflow, there is a large nett inflow of saline water.

During flood tide the saline wedge moves along the bottom at a velocity ranging from an average of 50 cm/sec in Reeves Channel to 10-15 cm/sec in Lake King. The ebb current of lake water attains its greatest speed in the upper part of the water column. At Metung where scour is greatest the ebb current was only detectable for the upper 9 m of the 18 m water column, while during flood tide the whole water column moves in response to the incoming flood tide (Table 3). Therefore it is clear that the scour is caused by the movement of saline bottom water into the Lakes.

## SEDIMENT TRANSPORT

The current velocity results collected over a 12 hour period at Metung were used to estimate the tidal volumes for the ebb and flood flow through the channel at Metung (P.W.D. 1980). These results were further analysed (King 1980a) so that flow volumes for the upper (0-7 m) and lower water layer were considered separately. The results are given in Table 4, and show that despite a large nett out flow over the complete ebb-flood cycle, there was a nett inflow through the lower section. This results in a nett landward transport of

TABLE 3

RESULTS SHOWING THE VARIATION OF THE NORMALIZED CURRENT VELOCITY, SALINITY AND TEMPERATURE WITH DEPTH AT PEAK EBB DISCHARGE ON THE 30.10.79 AND PEAK FLOOD INPUT ON THE 31.10.79 AT METUNG

<i>Tide</i>	<i>Depth (m)</i>	<i>Current velocity (m/sec)</i>	<i>Salinity (ppt)</i>	<i>Tem- perature (°C)</i>
Flood	1.8	0.36	19.3	15.5
	3.7	0.31	19.7	15.5
	5.5	0.31	19.7	15.5
	7.3	0.19	28.0	14.6
	9.1	0.13	30.3	14.5
	11.0	0.15	31.1	14.4
	12.8	0.10	32.3	14.3
	15.0	0.13	33.2	14.3
Ebb	1.8	0.41	19.6	15.5
	3.7	0.32	19.6	15.5
	5.5	0.26	23.0	15.3
	7.3	0.07	29.6	14.7
	9.1	0.09	30.8	14.7
	11.0	0.00	31.1	14.7
	12.8	0.00	31.1	14.7
	15.0	0.00	31.2	14.6

suspended sediment and saline water through the bottom section with every flood tide cycle.

The sediment scoured during flood tide is believed to make up a major part of the suspended sediment load of the saline bottom water. It follows that a large proportion of the eroded sediment has been transported back into Lake King, representing a significant input of suspended sediment. The nett outflow during the tidal cycle recorded, resulted in the export of suspended sediment, but without long term current data no firm statement can be made about the overall sediment budget of the Lakes. A nett retention of river sediment within the Lakes is expected however, based on a knowledge of the processes which act to retain sediment in an estuarine cell (Meade 1969).

Bedload transport is occurring as a result of the nett landward movement of the saline bottom water. This is most evident in Reeves Channel where sand is being transported landward in the form of sand waves. A thin veneer of sand is encroaching into the Lakes, along Reeves Channel and at present it has reached just east of Nunburner. Observations while diving, showed that deposition of this veneer of sand has halted the scour.

An interesting phenomenon observed while on the bottom in the 18 m channel at Metung, was a

bed of what proved to be rounded "pebbles" of mud rolled along the bottom during flood tide. No explanation can be given as to how they formed and it tends to complicate any attempt to understand the exact mechanism by which the fine grained sediment is being eroded.

## SALINITY

Salinity in the Lakes was the subject of a Parliamentary Public Works Committee inquiry in 1952; it concluded that there had not been an appreciable increase in salinity of the Lakes as a result of the artificial opening. Bird (1978) however provides evidence based primarily on *Phragmites* die back, to support a hypothesis of salinity increase since 1889, and the results of this investigation add substantially more weight to the conclusion of a salinity increase.

The scour channel that has developed in Reeves Channel now provides a significantly deeper passage for the exchange of water between the main body of the Lakes and Bass Strait. This has increased saltwater intrusion into the Lakes system by reducing the mean velocity of the lake water outflow but also a smaller proportion of the water column is affected by the outflow during ebb tide (Hinwood 1964). The results at Metung (Tables 3 & 4) show that 95% of the ebb flow volume passes through the upper 7 m of the 18 m water column, and there is a nett input of saline water through the lower section with each tidal cycle. Thus saline water is pumped into the Lakes and only exported after vertical mixing with lake water.

It seems incontestable that salinity increase within the lake system has occurred as a direct result of the artificial opening of the Lakes. The results of this study highlight the fact that a con-

TABLE 4

RESULTS OF FLOW VOLUME CALCULATIONS CARRIED OUT ON THE CURRENT VELOCITY DATA ACQUIRED AT METUNG ON THE 30-31.10.79. THE CROSS-SECTION OF THE CHANNEL WAS DIVIDED INTO AN UPPER AND LOWER SECTION BASED ON THE SALINITY AND TEMPERATURE STRATIFICATION.

<i>Date</i>	<i>Tide</i>	<i>Tidal volume (m<sup>3</sup>) Upper section (0-7 m)</i>	<i>Lower section (7 m-18 m)</i>
30.10.79	Flood	$7.2 \times 10^6$	$1.9 \times 10^6$
31.10.79	Ebb	$-11.8 \times 10^6$	$-6.8 \times 10^5$
Nett discharge		$-4.6 \times 10^6$	$+1.3 \times 10^6$



tinued deepening of the lake bottom due to scour is causing a steady increase in the salinity of the Lakes. It is contested that this is occurring due to the inability of the ebb current to flush out the saline bottom water which intrudes during flood tide. The ultimate result of the continual scouring of the channels will be the exposure of the barrier sands believed to underlie the lake deposits.

## CONCLUSION

Opening of the artificial entrance in 1889 has had a pronounced physiographical effect on the Gippsland Lakes, the flood tide currents have caused considerable scouring of the lake bottom sediment particularly east of Metung. The pattern of sediment transport has been altered, with the result that a tidal delta has formed near the entrance and suspended sediment is being distributed by tide induced currents within the Lakes. The salinity of the Lakes is believed to be steadily increasing by intrusion of saline water along the scour channels during flood tide, and little or no flushing of this lower layer of saline water during ebb tide.

An aspect of importance for bottom sampling within the Lakes is that bottom samples taken within the scour channels are samples of older exposed sediments and unlikely to be representative of present conditions.

## ACKNOWLEDGEMENTS

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## DUNE SYSTEMS ON CUSPATE FORELANDS EAST GIPPSLAND, VICTORIA

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**ABSTRACT:** This paper examines the configuration of the sandy shoreline and coastal dunes that occur between Mallacoota and Cape Howe in Eastern Victoria.

The major determinant of shoreline orientation is the diffraction and refraction of ocean swell around Tullaberga and Gabo Islands and the small sandstone reefs east of those islands. In the lee of the islands the coast has prograded as lobate to cusped shaped forelands and on these lie large fields of mobile dunes. The principal active dune is a sinuous transverse ridge. The Holocene evolution of the forelands and dune systems and the rates and processes of dune movement are examined. The spread of *Ammophila arenaria* may cause a fundamental change in the morphology of these active dunes.

### INTRODUCTION

Coastal dunes both active and stabilized by vegetation occur extensively in East Gippsland, with the largest fields adjacent to those shorelines open towards the south-west and therefore subject to strong onshore winds (Fig. 1). Few works exist on the geomorphology of the coastal area east of Lakes Entrance. Talent (1969) delineated only a coastal dune-swamp-sand complex of Quaternary age and Douglas (1974) did not differentiate between Pleistocene and Holocene coastal dune sands. The data on coastal geomorphology in the Land Conservation Council Report (1974) is of an elementary nature. Studies of coastal lagoons by Harford (1974) and Williams (1974, 1977) include detailed mapping of short sectors of this coast but the most comprehensive report on the coastal physiography to date is Rosengren (1978).

East of Mallacoota Inlet is the largest area of active transverse dunes on the East Gippsland coast and the present paper seeks to explain the evolution and modification of these coastal dunes.

### COASTAL GEOMORPHOLOGY

The coast between Mallacoota and Cape Howe consists of three distinct physiographic units (Fig. 2) (Pl. 7, fig. 1):

- (i) a narrow barrier that encloses a former arm of Mallacoota Inlet now swamp filled;
- (ii) broad cusped depositional zones and dune

fields behind Tullaberga and Gabo Islands;

(iii) an extensive area of active dunes that lie on a low rocky substrate adjacent to Iron Prince Reef. This reef is an outcrop of steeply dipping sandstones and shales of the Merimbula Formation and the coastline east of the reef consists of an irregular shore platform and boulder beach.

East of the Mallacoota entrance the coast describes a gentle curve with an alignment approximately  $240^\circ$ , almost parallel with the calculated wind resultant for Gabo Island. The barrier is thus little modified by transgressive dunes and consists of a single cliffed foredune with minor blowouts. These have lengthened into small parabolic dunes where the shoreline alignment becomes more east-west near Tullaberga Island and the onshore wind resultant becomes more effective.

Two projecting sandy depositional features on this coast are a result of wave refraction around Tullaberga and Gabo Islands. Deposition occurs in the equilibrium trap created where the refracted wave trains having passed around the island intersect and neutralize the effect of longshore drifting (Fig. 3). Progradation has taken place only from the landward shore and not from the lee shore of the islands. The features are best described as forelands (Gulliver 1896). That at Tullaberga displays a smooth rounded or lobate outline approximately 3 km along the base projecting 700 m seaward, while that at Gabo



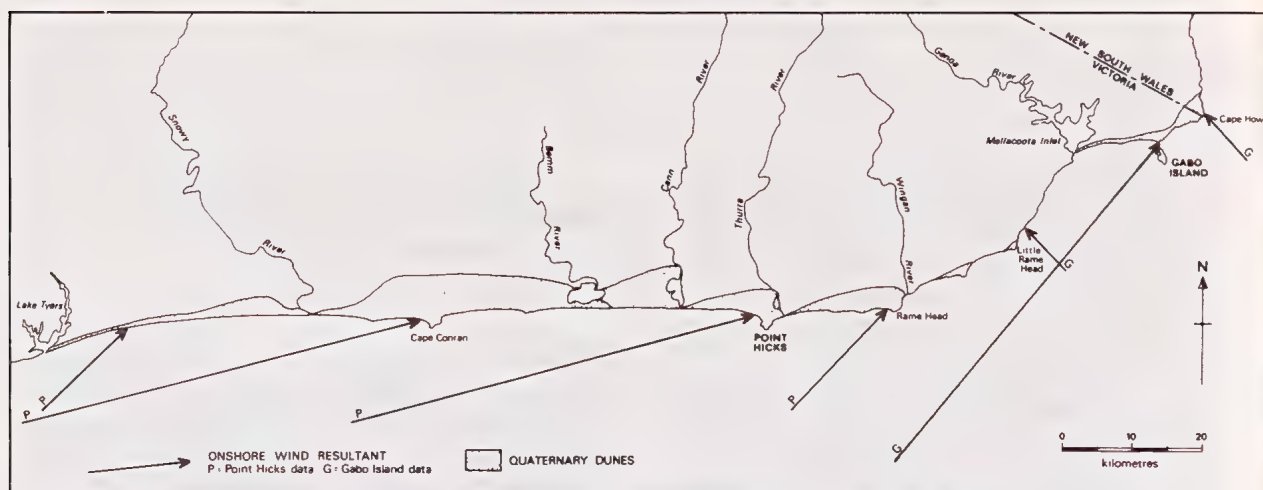


FIG. 1—Coastal dunes and onshore wind resultants, East Gippsland.

(Telegraph Point) is 7 km along the base, extends 1.5 km seaward and is more sharply pointed with sides concave seaward. Using Gulliver's criteria it may be considered a cusplate foreland.

The term cusplate foreland has been used to describe prograding shoreline sectors that are more or less triangular in shape with the apex of the triangle pointing seaward e.g. Wilson (1904), Johnson (1919) and more recently, Shepard (1963), Zenkovich (1967) and Komar (1976). The growth of forelands in the depositional zone adjacent to nearshore islands or shoals is only one of a number of situations where cusplate or crescentic accumulation features are built (Dolan *et al.* 1974). King (1972) defines a foreland as a cusplate formation without an enclosed lagoon and uses the term cusplate barrier for one that contains a lagoon. This latter condition originates where the foreland consists of looped or V-shaped bars or spits, or where two spits have connected an offshore island to the coast. Bird (1976) suggests that cusplate forelands are '... spits that have been enlarged by the accretion of ridges parallel to their shores, and stages in their evolution may often be deduced from the pattern of these ridges'.

Many cusplate forelands and tombolos do display a ridge and swale topography, but no such pattern may be distinguished on the forelands at Gabo and Tullaberga. On the Tullaberga foreland there are two ridges, a high inner ridge now largely destroyed by blowouts and a foredune also breached by small blowouts (Pl. 7, fig. 2). Sand released from these vegetated dunes has coalesced into a broad low transgressive dune sheet that has generally obscured the previous topography along the base of the foreland. The sand sheet is a series

of poorly defined transverse ridges 1 to 2 m high, the advancing dune front consisting of low narrow tongues that are invading the marshland around Lake Barracoota. The generation of the transgressive dunes is directly linked to the growth of the foreland. As the coast prograded towards Tullaberga the western shore of the foreland became oriented so that the prevailing westerly and south-westerly winds were more directly onshore winds. These became more effective in initiating blowout and parabolic dune movement—the alignment and extension of these dunes indicate the importance of this factor.

Telegraph Point is a symmetrical cusplate foreland tapering towards Gabo Island. The position and shape of the apex of the point changes in response to wave conditions—at times it is narrow and pointed but may be trimmed back to a blunted or more lobate outline (Pl. 8, fig. 3). During part of the 19th century, Telegraph Point extended to link Gabo Island forming a tombolo (Smellie 1890) but this connection was breached by storm waves in 1890 and since then the island has been separated by a channel up to 600 m wide.

The foreland has undergone three stages of development to reach its present configuration (Fig. 4). The mid-Holocene shoreline (established at or slightly above present sea level) was essentially a long straight barrier coast anchored in the east against the Devonian sediments and granites and with an entrance opening into Mallacoota Inlet in the west. Behind the barrier lay a lagoon, an arm of Mallacoota Inlet, extending as far as Lake Barracoota (Timms 1973, Williams 1977). The eastern limit of this lagoon was formed by a spur descending to the south from the granitic Howe

Range and this spur formed the point where the sandy shoreline was anchored to the mainland. Gabo Island is an offshore expression of this granitic spur.

The initial barrier shoreline shows little influence of wave refraction around Gabo Island. Its position is marked by a series of partly vegetated small parabolic dunes which suggest that the shoreline continued with an essentially straight alignment (Pl. 8, fig 3). These dunes became less active as they were gradually isolated from a sand supply by the subsequent development of the foreland.

The initially straight configuration of the barrier coast east of Mallacoota (Fig. 4A) indicates that relatively deep water lay between Gabo Island and the mainland. Even though the lee of the island created a sediment trap, a considerable subaqueous depositional phase was necessary before this could act as a reservoir for onshore transport. As the water shallowed and wave refraction from the dominant southerly swell became more pronounced, the barrier beach shoreline prograded as a spit diverging south-east towards Gabo Island.

Material for spit growth was supplied by longshore drifting generated from the west by westerly and south-westerly winds. The spit was shaped by the interaction of this drift with the refracted swell waves around Gabo Island. Refraction patterns from south-easterly swell established a second spit diverging south-westerly towards Gabo Island which linked with the western spit and enclosed a lagoon (Fig. 4B). Progradation was sufficient to extend the foreland as a tombolo joining Gabo Island (Allan 1872) but this was not dependent on successive beach ridge formation. Beach ridge formation was inhibited by the absence of gravel or shingle material in beach sediment, but particularly by the inability of primary sand binding species to cope with the exposed beach and backshore condition of a rapid supply of sand moved inland by strong and persistent winds. Along the beach face on the western flank of the foreland sand was lifted directly into transgressive dune formations, dominantly transverse ridges, and these invaded and partly filled the shallow lagoon. Aeolian sedimentation was thus contemporaneous with beach and barrier

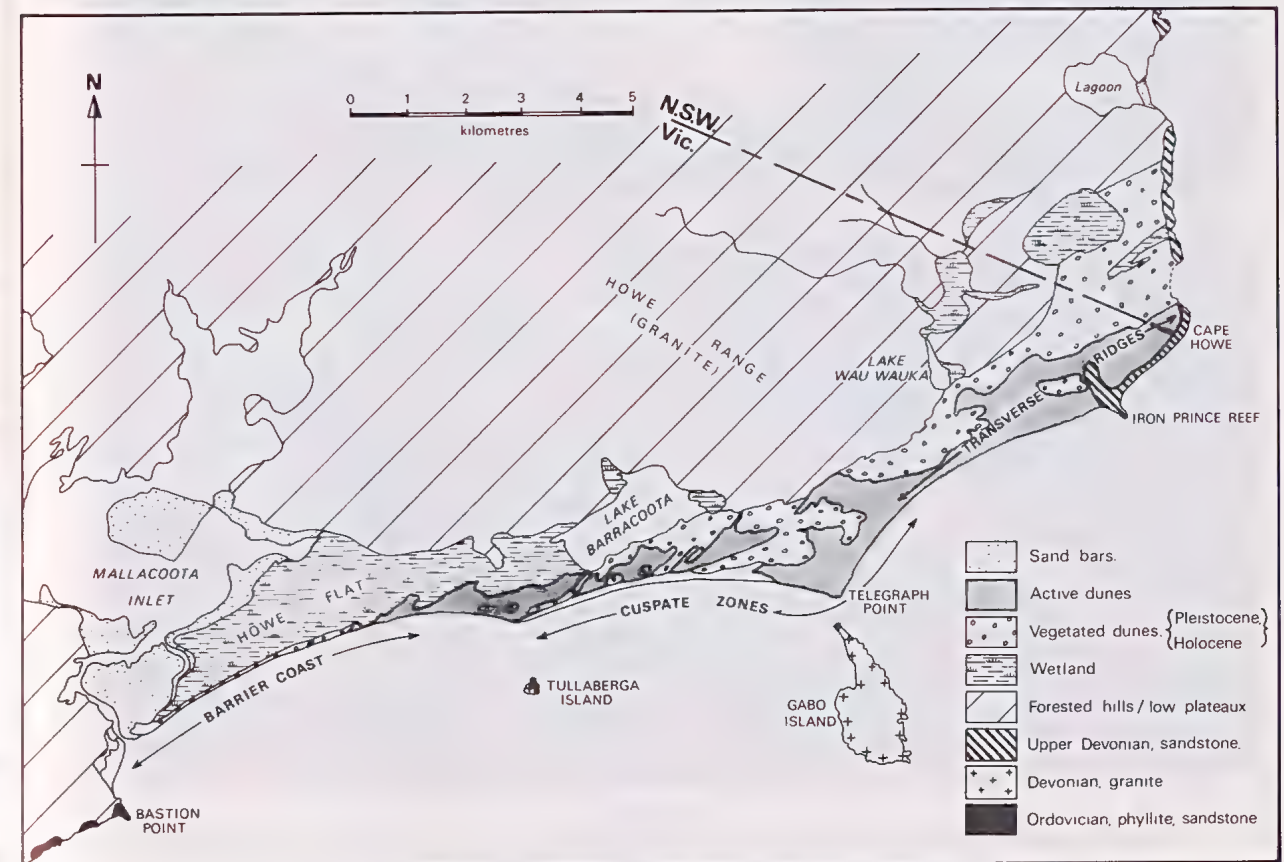


FIG. 2—Coastal physiography, Mallacoota Inlet to Cape Howe.





## PLATE 7

FIG. 1—Barrier and dune coast east from Mallacoota Inlet showing cusped zones behind Tullaberga and Gabo Islands.

FIG. 2—Dune complex on Tullaberga foreland.

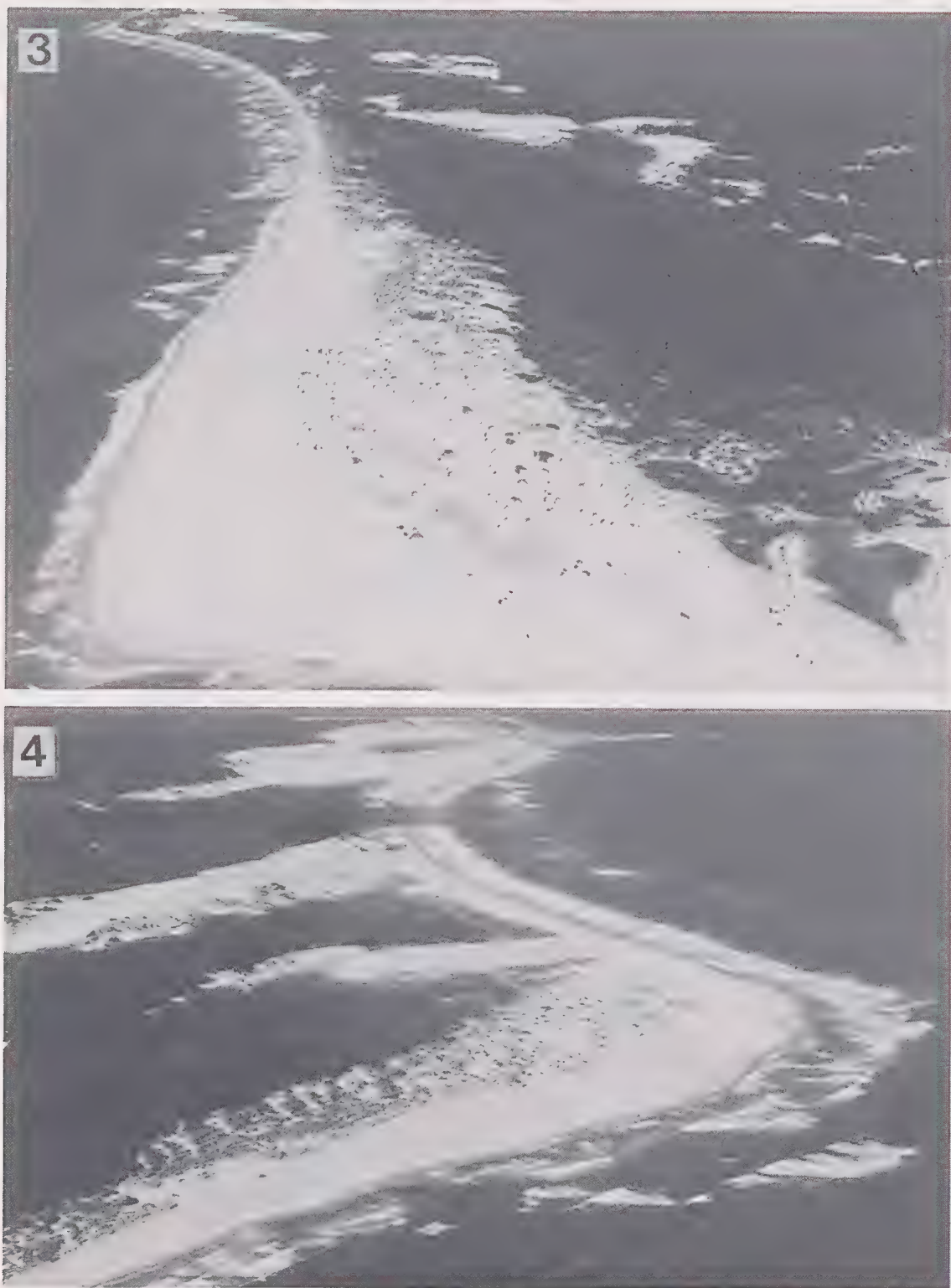


PLATE 8

FIG. 3—Western shoreline of Telegraph Point with *Ammophila* hummocks and foredunes.

FIG. 4—View east over Telegraph Point to Iron Prince Reef and Cape Howe. Note transgressive ridge in foreground being eroded at seaward end (See Plate 9, fig. 5).



sedimentation and not necessarily related to phases of marine transgression and regression (see Thom *et al.* 1978 for comparison with the New South Wales coast).

Sand supply was sufficient to reach the parabolic dunes of the earlier Holocene shoreline and these remained partially active—e.g. vertical aerial photographs taken in 1940 show transverse ridges extending to these from the western shore of the foreland.

Where the sand encountered taller scrub or woodland, a precipitation ridge developed and the transverse ridge form decayed into a series of

parabolic dunes. Stages in the transformation of an active ridge into a series of progressively stabilized parabolic dunes may be observed on the north-eastern edge of the foreland.

The final stage in the development of the foreland has been the severance of the tombolo to Gabo Island. During the 19th Century the tombolo was observed to be an intermittent link (Taylor 1866, Allan 1872) but since a major storm breach in June 1890 (Smellie 1890) a channel up to 600 m wide has been maintained between Telegraph Point and Gabo Island. In the past 40 years *Ammophila arenaria* has become established

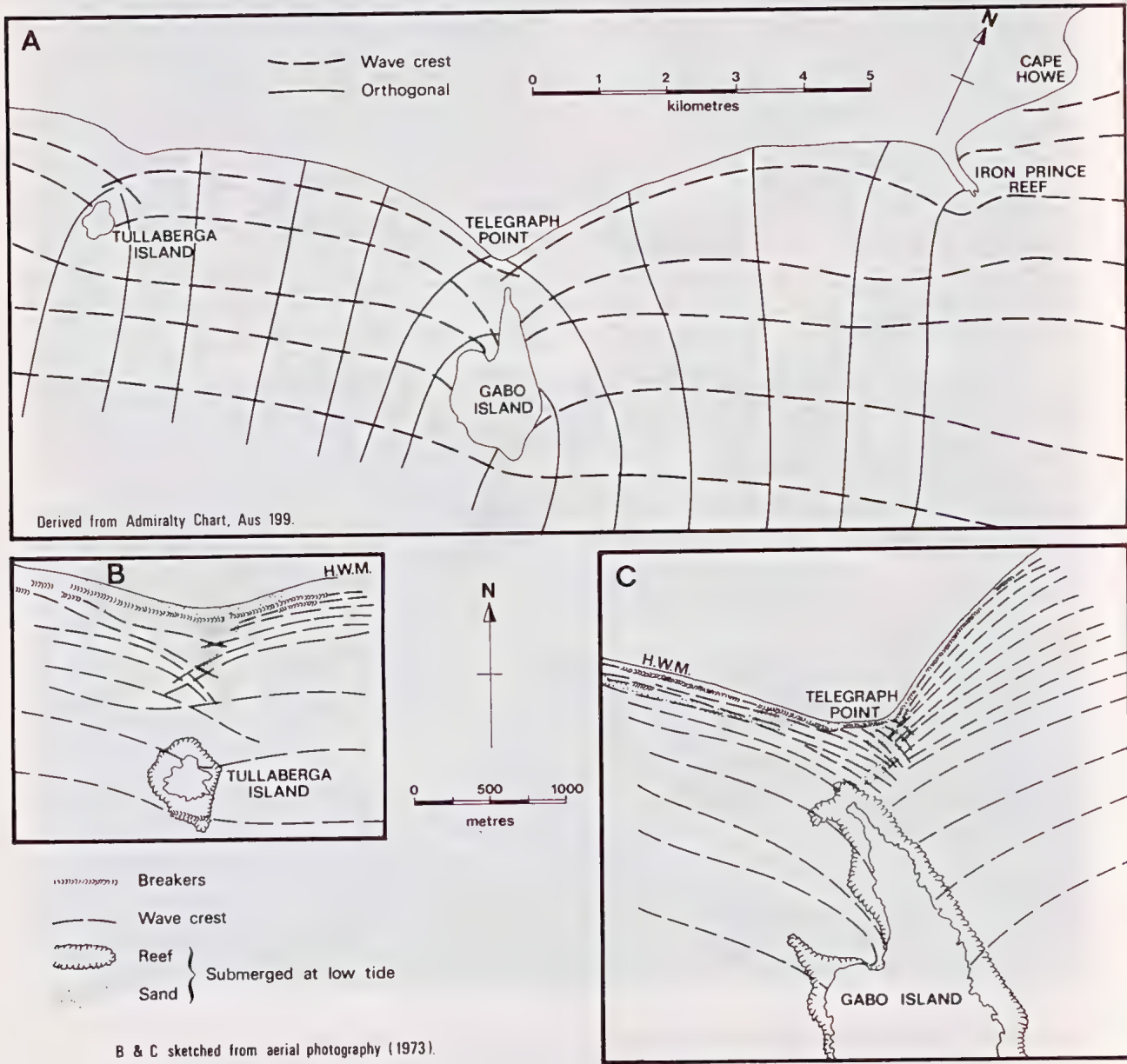


FIG. 3—Wave refraction patterns, southerly deep water swell direction with period 12 seconds.

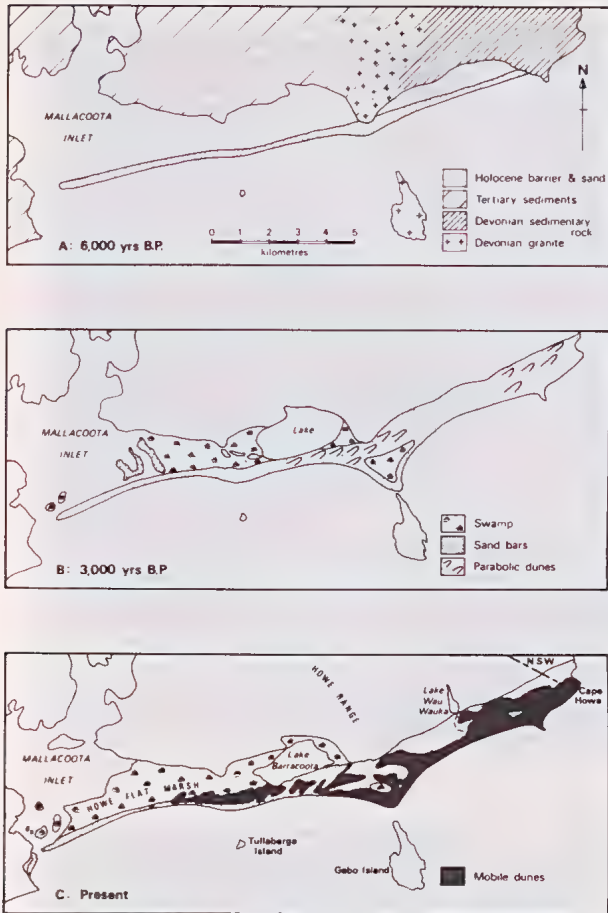


FIG. 4—Evolution of cusate forelands and coastal dunes. Dates provided are approximate only and are not based on specific radiometric determinations.

in the area leading to physiographic changes as discussed below.

The present configuration of the foreland is shown in Pl. 8, fig. 4. The western shoreline has a wide, low angle beach face behind which are *Ammophila* hummocks and lee dunes. Transverse ridges forming on the wide expanse of sand at the apex of the foreland coalesce as they are driven across the foreland from the south-west to north-east. Grass and scrub covered ridges and hummocks on the floor of the former lagoon mark the position of remnants of these migratory ridges. This topography is initiated by seepage from the base of the transverse ridge which encourages the growth of grass and scrub. This growth acts as a nucleus for sand deposition so that the hummocks become elongated and aligned roughly parallel to the base of the transverse ridge. On the eastern flank of the foreland the transverse ridges lie almost at right angles to the shoreline and their seaward ends are being eroded by waves (Pl. 9, fig.

5). Sand from the western shoreline is thus being transferred across the foreland through these ridges and part of this is then returned into the longshore transport system on the eastern shoreline to be carried further eastwards towards Cape Howe.

This cusate foreland plays a major role in shaping dune topography and determining the aeolian movement of sand along the coast and differs from the dynamics of other similar formations. Three types of cusate forelands may be identified with reference to their effect on sediment movement (Fig. 5): (a) stationary and stable (symmetrical projection with bilateral alimentation); (b) migratory (asymmetrical projection with unilateral alimentation); (c) stationary but with sand transmitted across the foreland as dunes (i.e. Telegraph Point).

East of Telegraph Point lies another extensive tract of active dunes consisting mainly of ridges oriented north-west to south-east (Pl. 8, fig. 4). These are in part derived from destruction of older vegetated parabolic ridges but the bulk of the sand is derived as free primary dunes on beaches east of

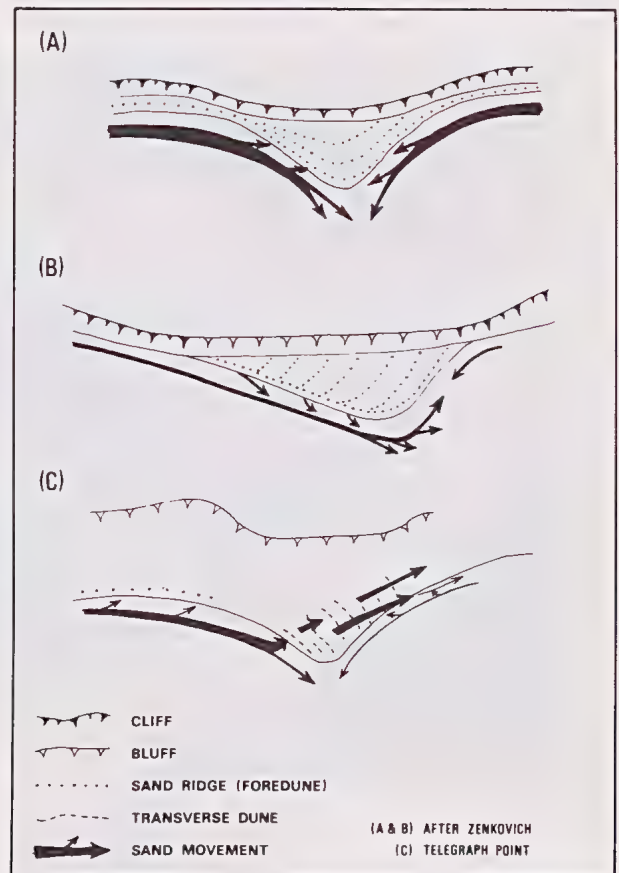
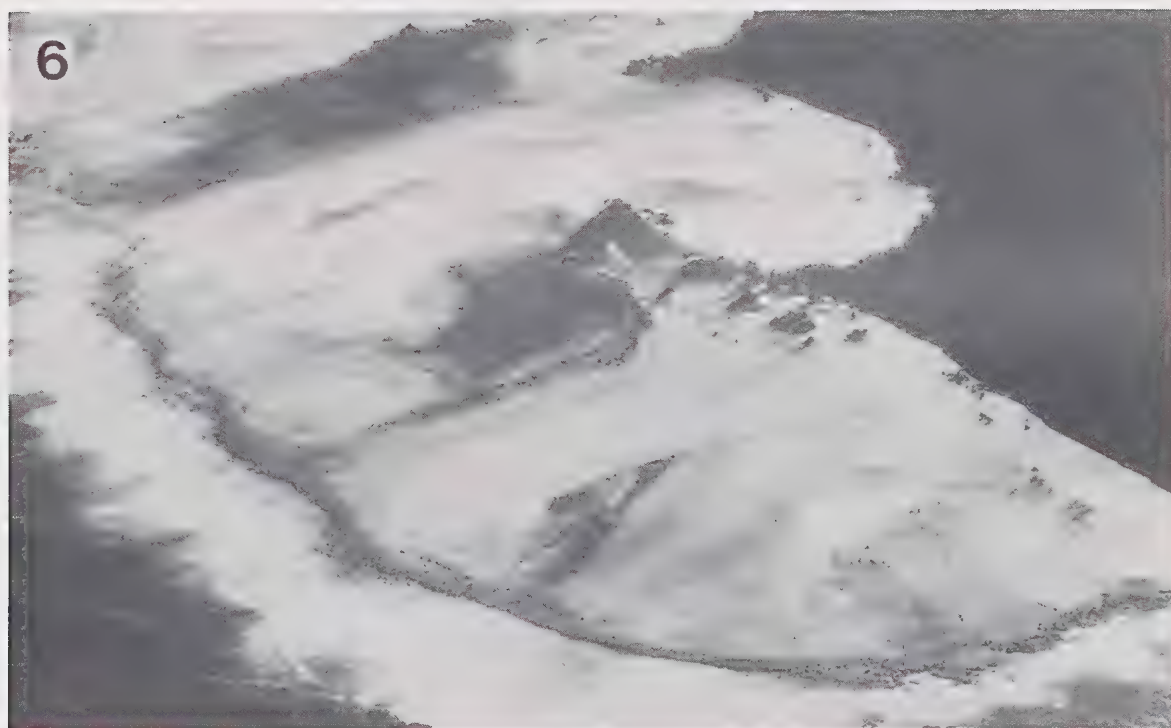
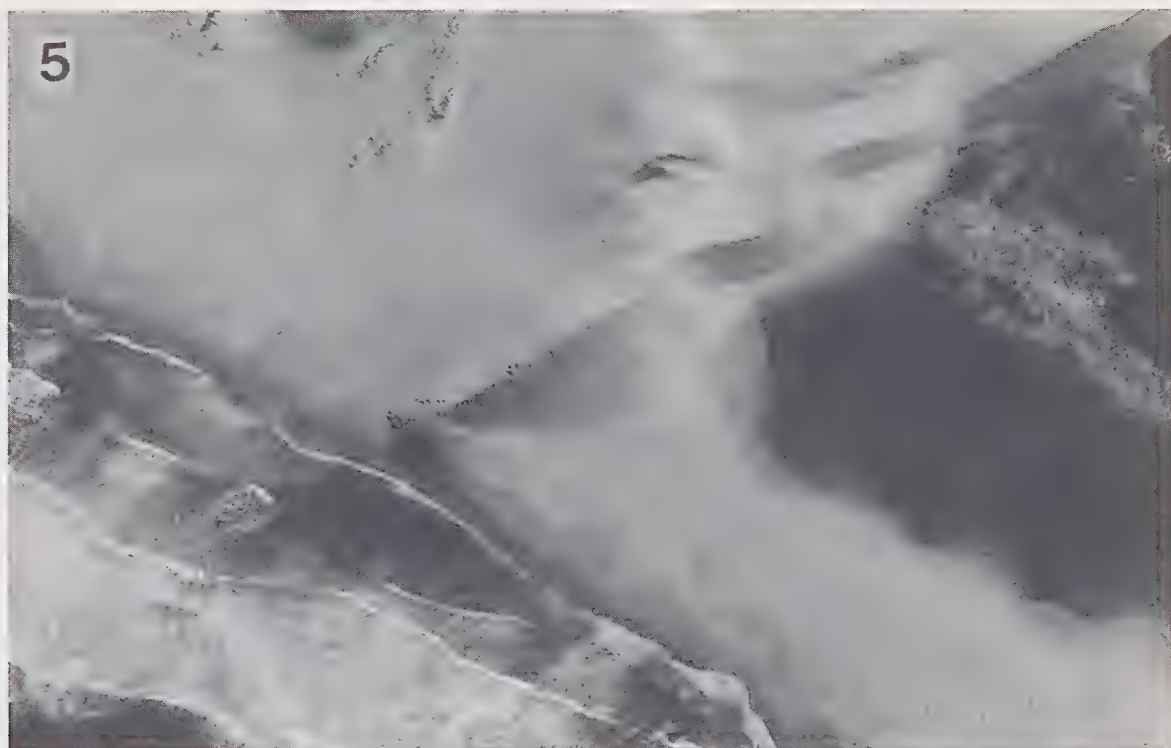


FIG. 5—Models of cusate foreland evolution.





## PLATE 9

FIG. 5—Erosion of transverse ridge east of Telegraph Point.  
FIG. 6— Transverse ridge systems at Cape Howe and Iron Prince Reef.

(All Plates are aerial oblique photographs by the author)

Telegraph Point in the depositional trap created by Iron Prince Reef. There are no vegetated foredunes along this sector so the sand passes directly from the beach to the transverse ridges first accumulating as low mounds or barchans. The larger transverse ridges are aligned at right angles to the onshore wind resultant with a low windward slope ( $5^{\circ}$  to  $10^{\circ}$ ) and a steep easterly slip face ( $18^{\circ}$  to  $33^{\circ}$ ). During summer months with a high incidence of north-easterly winds a temporary slipface develops towards the west but this is destroyed during winter and the sand transferred back to the eastern side of the dune (Fig. 6). Comparison of the position of ridge crests plotted from aerial photographs taken in 1940, 1961, 1966 and 1973 indicates mean annual movement eastward of up to 13 m on some ridges.

At Cape Howe where the coast turns to the north the transverse ridges are blown into the sea and the sand moves into the beach and coastal dune systems of southern New South Wales (Pl. 9, fig. 5).

## DISCUSSION

The wide spectrum of primary and transgressive dunes that occur between the Mallacoota Inlet entrance and Cape Howe illustrate well the respective roles of wind, waves, sand supply, vegetation and coastal orientation in dune formation (Fig. 7).

Eastward of the zone of entrance migration, wind action becomes increasingly more effective as the shoreline curvature brings the onshore resultant at a higher angle to the coastline. The high foredune ridge of the barrier is breached by small trough blowouts but these are now largely stabilized or have little inland extension. Revegetation allowing rebuilding of the foredune and a limited onshore sand supply account for the lack of transgressive dune development here (Fig. 7, Zones B & C).

The more transgressive dune formations in Zones D and E are a consequence of the increased sand supply on the forelands at Tullaberga and Gabo. The progradation of the coast at Tullaberga causes a widening of the beach and an increase in the area of sand exposed to wind action and also brings the shoreline curve around to face more directly to the onshore wind resultant. Broad but generally low parabolic dunes are the result as the area behind the foredune here is a marshland of sedge, reed or low scrub and of insufficient height to anchor a high precipitation ridge.

By comparison, the parabolic dunes in Zone E around Lake Barracoota are transgressive on older dune terrain with taller scrub and woodland

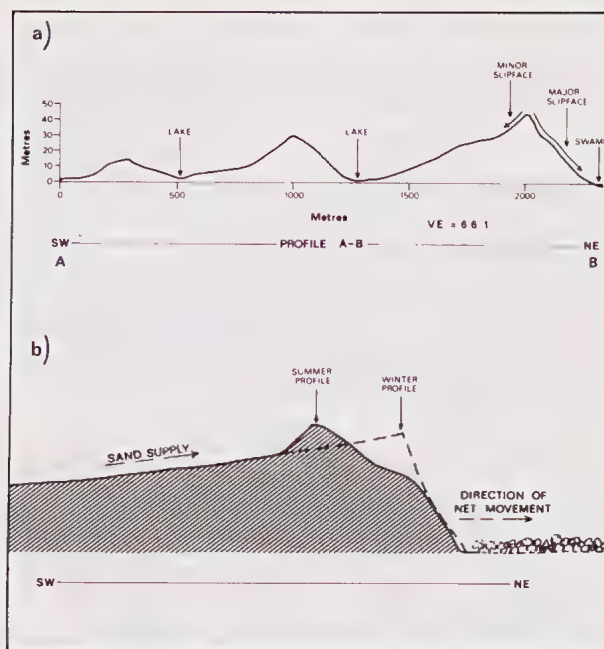


FIG. 6—Profiles of transverse ridges.

vegetation and hence these are of the more typical high and narrow parabolic form.

The occurrence of the transverse ridges in Zone F may be ascribed to the rapid progradation of the Telegraph Point foreland and the bulk emplacement of sand across this with little restraining influence of vegetation. The growth of the foreland has led to the removal of sand from the nearshore transport system (longshore drift) and its emplacement into the onshore transport system as beaches, spits and finally transverse dunes. Once initiated this dune transport process has moved sand intermittently eastward and transverse ridges have developed instead of other dune forms. This system relies upon continual nourishment from offshore or alongshore sand supplies being caught in the sediment traps of Telegraph Point and Iron Prince Reef. The active nature of the dunes at the present time indicates that currently, at least along this section of the coast, a phase of net onshore sand movement is taking place.

Along most of the ocean coast east of Wilsons Promontory there have been stages of foredune erosion over the last few hundred years. Some of the eroded sand has drifted eastward and may have augmented the supply available on the coast east of Mallacoota to be built into forelands in the depositional traps at Tullaberga, Gabo and Iron Prince Reef. In these sectors, sand has accumulated too rapidly to allow vegetated foredune



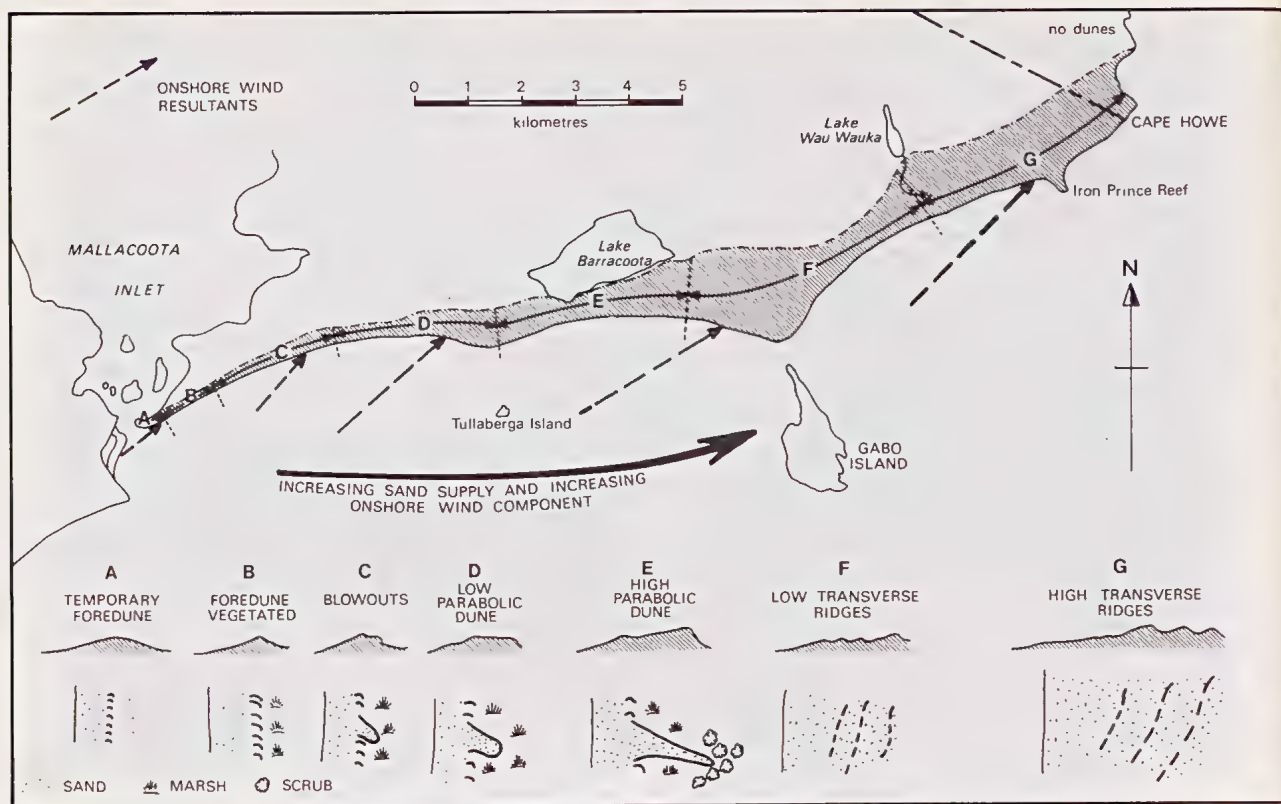


FIG. 7—Variation in coastal dunes—Mallacoota to Cape Howe.

building and instead, transgressive transverse ridges have developed. Progradation has at one stage been sufficient to form a tombolo to Gabo Island but the erosion of this over the past 80 years indicates that the rate of sand accumulation may now have decreased. If this is the case, then more extensive vegetation colonization on the cusate foreland may lead to the growth of foredunes and the elimination of the transverse ridges.

The role of primary sand binding species in building and maintaining foredunes and parallel ridges has been stressed by several authors (e.g. Cooper 1958, Olson 1958, Turner *et al.* 1962). The generally poor development of these systems in East Gippsland is in part a reflection of the ineffectiveness of the native primary sand binding species (*Festuca littoralis* and *Spinifex hirsutus*) in this area. Cooper (1958) noted that on the coast of Oregon (U.S.A.) the native dune grass *Elymus arenaria* provided a basis for foredune accumulation on sheltered sites but was unable to fulfil this role in the conditions of salt spray and strong wind action on exposed ocean beaches. Since the introduction of *Ammophila arenaria* to parts of the Oregon coast between 1900 and 1910, (Wiedman

*et al.* 1969) substantial vegetated foredune accumulation has occurred, diminishing the supply of sand to active transgressive dune systems inland.

Some parallels may be drawn between the Oregon and East Gippsland coasts in this regard. *Festuca* is rare in Gippsland and *Spinifex* is not a vigorous species on the more exposed ocean beaches, thus foredune and parallel ridge development has been restricted due to environmental limitations on plant growth.

As with the Oregon coast, the spread of *Ammophila arenaria* may be introducing a new factor in the physiography of coastal dunes in East Gippsland. As vegetated foredunes develop and the transverse ridge systems on Telegraph Point decay, less material will be released across the foreland and into the dune systems to the east. The Gabo foreland will then act more as a 'final' sediment trap rather than the 'transit' trap that it now is and as the existing transverse ridges are blown to Cape Howe and into the sea, a different dune regime—vegetated foredunes, blowouts, and parabolic dunes—will be established. Only continued sand movement on the western flank of the

Gabo foreland at a rate in excess of the capacity of vegetation to build foredunes can allow the transverse ridge system to be maintained.

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# RATE OF FORMATION OF HONEYCOMB WEATHERING FEATURES (SMALL SCALE TAFONI) ON THE OTWAY COAST, S.E. AUSTRALIA

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**ABSTRACT:** The development of honeycomb weathering on seawalls of nonmarine Lower Cretaceous greywacke built in 1943 and 1949 shows that under certain conditions this type of tafoni is a significant factor in the retrogradation of rocky coasts.

## INTRODUCTION

Tafoni, as originally described by Bourcart (1930), consist of large cavities developed in the vertical faces and overhangs of granitic cliffs and tors in Corsica. The meaning has since been extended to include honeycomb weathering (e.g. Jennings 1968). Geikie (1882, p. 335) used the term "honeycombed". Thus tafoni in the modern sense can be divided into:

1. Cavitation weathering (in the sense of Bourcart), and
2. Honeycomb weathering.

Both occur in the nonmarine greywacke of the Otway coast of south eastern Australia. Although these two types are not mutually exclusive, they can usually be separated respectively in size (large, small), morphology (broadly rounded; groups of relatively steep-sided cells reminiscent of honeycomb), and loci of development (on cliffs and boulder bases; on all aspects including horizontal surfaces where cavitation weathering never develops). Cavitation structures on the coast may include an area of honeycomb.

## TAFONI AND COASTAL RETROGRADATION RATE

The rate of coastal retrogradation varies according to the types of rocks forming them, and to the environments in which they stand. In the common environment (Mediterranean climate, microtidal, heavy swell) of the coast of Western Victoria, the rates of retrogradation of four rock types were found to vary by some orders of

magnitude (Gill 1973a). As one of these rock types, the Otway greywacke, is affected to an exceptional degree by honeycomb weathering (Gill 1972, fig. 3), a means of quantifying this process was sought in order to assess its significance for coastal retrogradation. The best evidence was derived from stone retaining walls of known age that have developed a considerable amount of honeycomb weathering much more rapidly than previously estimated. The dates of construction of the walls were verified with the construction authority, and it was established that quarried stone (i.e. with fresh faces) was used.

Before the dated honeycombed walls were investigated (by N.H.M.), old photographs were examined for change, e.g. Jutson (1949, pl. 5, fig. 1), but the scale of these photographs and the lack of sufficient detail prevented adequate quantification. However, at Jutson's site 0.5 km S.W. of Point Grey, Lorne, six subspherical concretions shown in the 1949 photograph are now reduced to three and a half, a mass of protruding honeycomb has been broken away, and new honeycomb is developing on the fracture face.

## HONEYCOMB FORMED SINCE 1943

Southwest of the mouth of St. George River on the Great Ocean Road, S.W. of Lorne, where a small perched rivulet crosses the road and drops to a boulder beach (Gill 1973b, pl. 6), a wall was constructed in 1943 to support the road (Pl. 10, fig. 1). The wall was built of fairly well squared blocks of greywacke from the Country Roads Board quarry







in Lorne. Workmen inscribed their names in the wet cement at the time of building, *viz.* "S.A. Carr 1943" and "P.W. 1943". Honeycombed rock is not used for building walls, as can be seen in the rebuilt N.E. section of this wall, and in walls on the high side of the Great Ocean Road which escape this type of weathering. The N.E. part of this wall was washed away in a storm and had to be rebuilt. That considerable honeycomb weathering has developed since the wall was built in 1943 is also shown by:

1. The honeycomb formed in the cement as well as in the rock (Pl. 10, fig. 2).
2. Some cells have only a fine sliver of rock between cell and cement. Such a delicate structure could not of course be built into the wall.

#### HONEYCOMB FORMED SINCE 1949

The Great Ocean Road between Spout Creek (Eastern View) and Grassy Creek (Point Castries) includes an unstable area known as Clarke's Slip (Pl. 11, fig. 1). Clayey siltstone dips seaward at 40° oblique to the coast. The retrogradation rate of this siltstone is 100% greater than that of the accompanying greywacke, so the toe is more rapidly eroded. It is calculated that since the sea returned to its present level about 6,000 years ago in this area, the siltstone toe has retreated ~100 m but the accompanying greywacke toe only ~50 m. These are approximately the widths of the shore platforms in the respective lithologies. Where the siltstone outcrops, the shore is incurved. As slips here place the road in jeopardy, some control is necessary. In 1949 a wall was built at the toe of a slip to prevent it being eroded by the sea. It consisted of a double row of piles with rockfill. At the north (more protected) end, a short revetment wall was built of greywacke blocks from the Lorne quarry. This wall does not receive direct wave attack, but swash has eroded a nip at its base, and wave splash falls on the face above the nip. Recently, large masses of rock have had to be placed in front of the wall to protect the nip from further erosion (Pl. 11, fig. 1). All this honeycomb has developed in the past 30 years. The cells are more frequent and larger at the seaward end of the wall, showing that splash from the sea is a factor in its development. Walls built of the same rock

on the same coast, but above the splash zone, have not developed honeycomb.

#### MODE OF HONEYCOMB FORMATION

The structures in the 1943 and 1949 walls throw light on the mode of formation of this type of weathering. Rocks *in situ* and the parts of the wall constantly washed by the sea are smooth, being subject to constant abrasion—the Schlict-zone—whereas honeycomb occurs in the higher supratidal zone where the rocks are frequently wet by spray—the Spritzzone. The latter is between the top of the abrasion zone and the bottom of the black alga *Verrucaria* zone. At Artillery Rocks the swash smooths the supratidal zone between carbonate concretions, but where pedestal rocks occur, honeycomb forms on the stems (Gill *et al.* 1977, pl. 9, fig. 1).

However, honeycomb weathering is not formed by marine action only, because one of the most spectacular developments of it is in the Swallows Cave on the Sheoak River at the site of a waterfall about a kilometre from the coast. As spindrift develops no honeycomb on stone walls on the Great Ocean Road not far above the shore, it cannot produce it in a river valley about 1 km inland with a rainfall about 1,000 mm p.a. In the same valley, small rare patches of honeycomb occur on cliffs and bluffs where pieces of rock have fallen away to leave fresh rock faces. The remaining rock surfaces are covered with a weathering crust. No such crust occurs on the honeycomb zone at the coast, but begins in the algal zone above, where it often domes, cracks, and produces scale. Some kind of intermittent wetting occurs at all honeycomb sites. Some claim that salt (NaCl) is the sole agent, but S.E.M. examination (see below) and the occurrence of very well developed honeycomb at sites like the Swallows Cave rule this out for the Otway region.

As shown in the figures, different blocks in the same stone wall are affected to different degrees by honeycomb weathering, indicating that there is some lithologic control (as well as degree of wetting) of the process. Many blocks are subject to perimeter weathering. Often the honeycomb cells are aligned with joint planes, which suggest that stresses set up in the strata during tectonic movement have developed preferential orientations in the matrix of the rock.

#### PLATE 10

FIG. 1—Seawall of quarried greywacke built in 1943 on the Great Ocean Road S.W. of St. George River, Lorne district, Victoria. Note the "nip" at the base of the wall, and the honeycomb weathering.

FIG. 2—Detail of honeycomb weathering on wall face. The concrete cement is also weathered.



With the help of Dr. C. M. Barton, the length versus width of cells was checked on an image analyzer to quantitatively determine the degree of elongation in the vicinity of a major joint. The ratios in three samples were 0.63, 0.70, and 0.72 respectively.

## SCANNING ELECTRON MICROSCOPE EXAMINATION

ERS and EDG spent a considerable time examining both weathered and fresh (broken) faces of greywacke in which honeycomb has developed. These faces present a strong contrast. In the former the quartz grains are bared, they stand out from the surface of the rock, and are often bounded by cracks showing that they are in process of being released. Secondary minerals on the surface of the rock are characteristic. Two types are dominant—carbonates and clays. Calcite was determined in a secondary coating on quartz grains in many places. The secondary clay minerals were also present as coatings, but in addition occurred as crystals, viz. small ( $\sim 5\mu\text{m}$ ), numerous crystals standing up above the surface of the rock. Weathered feldspars were recognized. One series of SEM examinations showed minute (5–10  $\mu\text{m}$ ) gypsum crystals ('flowers') as well as crystalline calcite on the weathered surface. Halite crystals were found in only one place and they were on the surface of rock, not in crevices where their growth could prise grains apart.

By contrast, the fracture surface shows the grains to be covered by clay skins, and in places there are smooth clay surfaces interpreted as casts of grains. Many pores in the rock are filled with platy clay deposits, and an interstitial zeolite was noted. The secondary minerals seen on the weathered surface are absent. Both the weathered and fracture surfaces show the rock to be porous. The quartz grains are angular to rounded. Bradley *et al.* (1978) found that salts are significant in forming cavitation weathering on inland granites in South Australia.

The above results are consistent with the

petrographic description of Otway greywacke. Laumontite has been recorded in these rocks, and is probably the zeolite noted. The presence of gypsum fits the observation of secondary pyrite both as platy deposits in joints, and as nodules (Gill *et al.* 1977). The whole formation is rich in carbonates that constitute two generations:

- (a) Penecontemporaneous concretions, pre-tectonic.
- (b) Post-tectonic joint deposits.

The porosity noted in the rock would allow easy migration of the solutions from which the secondary minerals were precipitated.

## CONCLUSIONS

Under favourable conditions, honeycomb weathering can develop rapidly enough to be a significant factor in coastal retrogradation. It is estimated that tafoni accounts for  $\sim 10\%$  of the coastal erosion of the Otway Group greywacke in S.E. Australia.

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## PLATE 11

FIG. 1—Greywacke revetment to piled structure built in 1949 at Clarke's Slip between Spout Creek and Point Castries on the Great Ocean Road at Eastern View, Victoria. The wall has been so weakened by honeycomb weathering that the large rocks in the foreground have been emplaced to protect the wall. The tide is high and the sea exceptionally calm.

FIG. 2—Detail of the honeycomb weathering. The wall is in the marine splash zone.

## PLATE 12

Calcite concretion (without honeycomb weathering) on greywacke pedestal with strongly cellular honeycomb which is being eroded at the base by swash. The sea is to the right. The molluscs are *Littorina*, which inhabit the splash zone. Artillery Rocks, Otway coast, Victoria.









PLATE 12

# ULTRAMAFIC AND GABBROIC NODULES FROM THE BULLENMERRI AND GNOTUK MAARS, CAMPERDOWN, VICTORIA

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**ABSTRACT:** A diverse assemblage of well preserved ultramafic blocks is described from agglomerates around Lakes Bullenmerri and Gnotuk. They were ejected during initial maar eruptions of nepheline basanite magma south-west of Camperdown late in the Quaternary. Nodules include metaperidotites, metapyroxenites, peridotites, pyroxenites, hornblendite and essexite. Contacts in nodules establish relationships between different rock types. The metamorphic nodules show textures such as curved crystal lamellae, recrystallisation and mylonitisation. Their mineralogy indicates an upper mantle origin, with metapyroxenites forming lenticular bodies within predominant lherzolites. Some metamorphic nodules show evidence of hybridisation and Mg-depletion due to local partial melting. The resultant liquids yielded the clinopyroxene and olivine cumulates, which show increased Ti and Fe. A similar, more hydrous magma may have formed the intrusive hornblendite which occupies fissures that cut all the other rocks except the essexites.

## INTRODUCTION

The limited denudation of the tuff rims around Lakes Bullenmerri and Gnotuk suggests that maar-producing volcanism ceased there in late Quaternary times. The shapes of the lake-filled depressions indicate that several related eruption centres were involved. Bedded tuffs and agglomerates similar to those seen in other local maars such as Elingamite, Purumbete and Keilambete are well exposed around the lakes and at many points they are seen resting on Miocene marine sediments. In most places tuffs dip at 35° to 50° inwards, towards the eruption centres. The basal few metres of tuffs and agglomerates abound in ultramafic nodules of remarkable variety, up to 12kg in weight and 30 cm diameter. These are associated with large blocks of basalt and gabbro, some weighing several tonnes and exceeding 2 m diameter. Beach sands are composed largely of fresh olivine, pyroxenes, amphiboles and scattered garnet with rarer spinel, ilmenite and anorthoclase.

Spinel lherzolite and pyroxenite nodules occur almost to the exclusion of other ultramafic rocks at most Western District localities (e.g. Mt. Shadwell, Mt. Leura, Mt. Noorat). By contrast the assemblages at Lakes Bullenmerri and Gnotuk show a predominance of nodule types that are extremely rare elsewhere. Most notable are garnet

and spinel pyroxenites, olivine and amphibole-bearing hybridised garnet pyroxenites, amphibole peridotites and rare mica peridotites. Some nodules are mylonitised. These rocks lack plagioclase, in contrast to the garnet-plagioclase-pyroxene rocks from The Anakies and Mt. Franklin (Wass & Irving 1976).

Grayson & Mahony (1910) first described the geology of Lakes Bullenmerri and Gnotuk in detail, describing their characteristic rock types. They noted an isolated fine-grained garnet pyroxenite nodule and recorded garnet in the beach sands. Thin sections of essexite nodules were figured. Ellis (1976) examined the relationship between deep-seated blocks and their host lavas at Bullenmerri and elsewhere. He recorded a wide range of inclusions associated with the nepheline basanite but no garnet-bearing nodules. Aspects of the general geology of the maars are recorded by Gregory (1904), Ollier & Joyce (1969, 1973), Gill (1964) and Joyce & Evans (1976).

Nodules vary from angular, impact-spalled fragments and joint blocks to types having one or more smooth, rounded surfaces. Some garnet pyroxenites show garnets eroded into smooth, concave pits on rounded surfaces. Alteration of the nodules is minimal although most garnets have a thin margin of grey, fibrous 'kelyphite' (a fine-grained intergrowth of spinel, orthopyroxene and



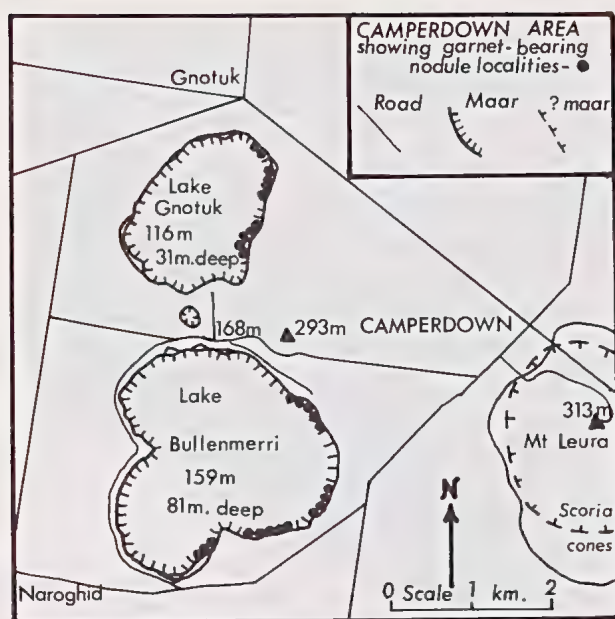


FIG. 1—Locality map of Camperdown area.

plagioclase pseudomorphing the garnet). Garnet-bearing ejected blocks are common along the eastern shores of both lakes (Fig. 1) where the lower agglomeratic tuff horizons intersect the shore. None have been found on the western shorelines. Other ultramafic blocks show a similar distribution, although isolated examples are found along the western shores. Xenoliths of country rocks include Tertiary mudstones, marls and limestones which are largely unaltered, although some have been baked.

An outcrop of nepheline basanite circling Lake Gnotuk and part of Bullenmerri may have been a flow from Mt. Leura, predating the maar eruptions. It contains many ultramafic nodules but no garnet-bearing types were seen. The small amount of basanitic lava adhering to a few nodules from the tuffs contains abundant xenocrysts of olivine, amphiboles and pyroxenes set in a glassy groundmass.

This paper describes the field aspects of the Bullenmerri-Gnotuk nodules. The assemblage is unique in Australia and the locality should be of international significance when detailed geochemical work has been carried out.

## CLASSIFICATION OF NODULES

The complexity of the rocks comprising the nodule assemblage makes their classification extremely difficult (Table 1). As well as distinctive mineralogy, mixing, metamorphic, igneous and cumulate textures are recognisable in most rocks. Other specimens show contacts between different

TABLE 1

### CLASSIFICATION OF ULTRAMAFIC AND GABBROIC NODULES FROM BULLINMERRI AND GNOTUK

#### A. METAPERIDOTITE GROUP

1. Garnet Sub-group—Not represented
2. Spinel Sub-group
  - Harzburgite V
  - Enstatite + Cr diopside  $\pm$  spinel lherzolite C
  - Phlogopite + Cr diopside  $\pm$  spinel  $\pm$  enstatite lherzolite V
3. Feldspar Sub-group—Not represented
4. Mg-depleted Sub-group
  - Mylonitised and fused lherzolites O
  - Amphibole + Cr diopside  $\pm$  spinel lherzolite. Kaersutite ovoids, some with spinel cores and Cr diopside mantles A
  - Cr diopside  $\pm$  spinel peridotite to dunite S

#### B. Metapyroxenite Group

1. Primary Sub-group
  - Primary garnet pyroxenite. Coarse orange to pink garnet, green clinopyroxene, minor orthopyroxene and spinel S
  - Coarse spinel pyroxenite. Large green clinopyroxene with orthopyroxene lamellae. Large black spinel R
2. Garnet exsolution Sub-group
  - Transitional spinel-garnet pyroxenite. Spinel with garnet mantles and orthopyroxene lamellae in relict clinopyroxene replaced by garnet O
  - Exsolved garnet pyroxenite O
3. Hybridised Sub-group
  - Complex hybridised pyroxenites  $\pm$  spinel, olivine, garnet, kaersutite, Cr diopside, enstatite and xenocrysts from other groups C

#### C. Peridotite-Pyroxenite Group

1. Magmatic Sub-group
  - Complex hybridised peridotites  $\pm$  kaersutite and xenoliths of A2, B1 & C2 Sub-groups O
  - Augite peridotite (wehrlite) O
  - Augite clinopyroxenite O
  - Orthopyroxene + clinopyroxene pyroxenite (websterite) S
2. Cumulus Sub-group
  - Amphibole peridotite. Olivine with amphibole intercumulus C
  - Clinopyroxene peridotite. Olivine with clinopyroxene intercumulus O
  - Amphibole clinopyroxenite. Clinopyroxene with amphibole intercumulus  $\pm$  biotite S

#### D. Hornblendite-Essexite Group

1. Hornblendite Sub-group
  - Hornblendite  $\pm$  clinopyroxene, biotite & ilmenite C
2. Essexite Sub-group
  - Alkali gabbro (essexite) A

A—abundant; S—sparse; C—common; R—rare; O—occasional; V—very rare

phases, indicating relationships. Grouping is based on these factors, in addition to petrographic assessment and electron microprobe analyses of constituent minerals (Tables 2 to 4). The assemblage is significant due to the general absence of feldspars and the predominance of amphibole peridotites. Interpretation of rock type origins and comparisons with other nodule localities are made with reference to recent literature.

#### METAPERIDOTITES

Enstatite—Cr diopside—spinel lherzolites predominate at most nodule localities, having olivine of Fo<sub>87-92</sub> (Frey & Green 1974), enstatite of Mg<sub>90</sub> and accessory pleonaste to picotite with 1 to 2% Cr<sub>2</sub>O<sub>3</sub>. Similar nodules are common at Lakes Bullenmerri and Gnotuk, but amphibole peridotites predominate. Amphibole is very rare at the numerous other eruption centres around Camperdown.

The amphibole peridotites have olivine of Fo<sub>82-88</sub> and little or no enstatite. In hand specimen, amphiboles (predominantly kaersutites) range from light fawn and olive-brown to almost black. The virtual absence of orthopyroxene and Mg-depletion of the olivine may be due to Mg substituting into the development of amphibole. When compared with those of the hornblendites, the peridotite amphiboles are lower in Ti and

higher in Al, a feature identified with high-pressure amphiboles by Best (1974). Amphibole compositions and the presence of orthopyroxene in some nodules indicates origins in the upper mantle (Green, 1973). Amphibole occurs either as individual crystals or as ovoid, interlocking patches. Orientation of the patches often produces a distinct banding in the peridotites, which may in turn be intersected by planes of finer, granular amphibole (Fig. 4, Bm114). Bright green Cr diopside appears as quite large, irregular patches or scattered crystals within the olivine matrix and often forms broad mantles around the amphiboles. Thin bands of Cr diopside-rich peridotite run parallel to the amphibole lineation in some nodules. A few amphiboles have spinel cores. The amphibole peridotites probably represent the results of partial melting in the upper mantle lherzolites under wet conditions (Vinx & Jung 1977). Amphiboles similar to those from Bullenmerri are recorded from nodules in the Westeifel maars (Becker 1977).

Mylonitised peridotites are not uncommon at Bullenmerri, showing a semi-foliated, sugary texture with finely granular olivine (Fo<sub>75-85</sub>). Cr diopside and amphiboles are drawn out into augen and shard-like forms, often with interstitial glass. The metaperidotites are frequently intruded by hornblendite, which is rich in reddish-brown biotite in the reaction zones adjoining wall rock. Occa-

TABLE 2  
ELECTRON MICROPROBE ANALYSES OF PYROXENES IN NODULES FROM BULLENMERRI AND GNUTUK

	CLINOPYROXENES						ORTHOPYROXENES			
Phase	A4	B2	B2	B3	B3 + C1	C2	B1	B2	B3	B3 + C1
Specimen	Gn151	Bm116	Bm20	Bm55	Bm92	Bm83	Gn168	Bm153	Bm55	Bm92
SiO <sub>2</sub>	51.44	52.11	52.20	51.41	50.70	51.11	53.42	54.43	57.87	51.33
TiO <sub>2</sub>	.78	.59	.36	.66	1.67	1.50	.07	.20	.13	.87
Al <sub>2</sub> O <sub>3</sub>	5.74	5.60	7.22	6.32	7.78	8.10	4.11	4.15	4.68	8.04
FeO*	5.66	4.83	4.12	3.59	7.39	7.10	11.67	11.60	5.53	13.73
MnO	.09	.13	.05	.07	.12	.16	.24	.18	.15	.25
MgO	15.72	14.55	13.59	14.52	12.72	12.75	28.85	29.94	31.30	24.02
CaO	18.72	21.67	21.14	21.85	18.58	18.10	.54	.70	.44	1.76
Na <sub>2</sub> O	1.29	.83	1.25	1.14	1.68	1.74	.04	.02	.08	.13
K <sub>2</sub> O	0	0	0	.01	0	0	0	0	.02	0
Cr <sub>2</sub> O <sub>3</sub>	.24	.05	.16	.24	.03	.03	.11	.04	.21	0
NiO	.03	0	.01	.07	.08	.08	.01	.09	.10	.07
Total	99.51	100.36	100.10	99.88	100.74	100.67	99.06	100.84	100.51	100.20
Ion%										
Mg	48.9	44.3	43.7	45.0	42.1	42.8	80.6	81.0	90.2	72.8
Fe	9.9	8.3	7.4	6.2	13.7	13.4	18.3	17.6	8.9	23.4
Ca	41.2	47.4	48.9	48.8	44.2	43.8	1.1	1.4	0.9	3.8

\* Total iron as FeO (Fe<sup>2+</sup>).



TABLE 3

ELECTRON MICROPROBE ANALYSES OF GARNETS AND OLIVINES IN NODULES FROM BULLENMERRI AND GNUTUK

Phase	GARNETS					OLIVINES			
	B1	B2	B3	B3	B3 + C1	A2	A4	C1	C2
Specimen	Bm20	Bm122	Bm103	Gn8	Bm92	Bm179	Bm129	Bm108	Bm103
SiO <sub>2</sub>	42.71	41.29	41.65	40.91	42.09	40.87	39.26	39.49	38.59
TiO <sub>2</sub>	.12	.03	.10	.05	.38	0	0	.05	.01
Al <sub>2</sub> O <sub>3</sub>	22.70	22.78	22.91	23.14	22.03	.02	.03	.01	.02
FeO*	11.42	13.67	12.89	13.85	14.79	8.96	12.63	16.57	22.55
MnO	.23	.56	.40	.57	.32	.06	.21	.15	.15
MgO	16.54	15.65	16.70	16.18	14.98	49.50	46.73	42.42	37.94
CaO	6.28	5.77	5.70	5.73	5.45	.05	.05	.06	.10
Na <sub>2</sub> O	.01	.03	.06	.03	.01	.01	0	.05	.01
K <sub>2</sub> O	0	0	.01	.01	.01	.01	.01	0	0
Cr <sub>2</sub> O <sub>3</sub>	.24	.13	.08	.13	.12	0	0	.03	.06
NiO	.02	.08	.11	.07	.08	.31	.42	.25	.22
BaO	0	0	.14	.14	.12	0	0	.09	.11
Total	100.27	99.99	100.75	100.81	100.38	99.79	99.34	99.17	99.86
Ion%									
Mg	60.2	57.0	59.6	58.4	55.1	90.8	86.8	82.0	75.0
Fe	23.4	27.9	25.8	28.0	30.5	9.2	13.2	18.0	25.0
Ca	16.4	15.1	14.6	13.6	14.4	—	—	—	—

\* Total iron as FeO (Fe<sup>++</sup>).

sionally, thin partings are lined with biotite which is deep green in hand specimen and amphibole is absent. Contacts between metaperidotites and pyroxenites of the peridotite-pyroxenite group are sharp and planar, a feature also noted by Irving (1974a) and Wilshire & Shervais (1976).

#### METAPYROXENITES

The metapyroxenite group comprises nodules of up to 5 kg which contain spinel and/or garnet. They range from simple, equigranular, homogeneous types, through a series of exsolution phases to complex multi-phase varieties with olivine, amphibole and Cr diopside. The latter are profoundly disrupted, hybridised rocks containing xenocrysts with curved lamellae, rare schlieren from metaperidotite phases and minerals showing a wider range of compositions. Nodules typically contain pyrope-rich garnet as pink to orange-red anhedral crystals averaging 3 mm diameter, but up to 25 mm in rare cases. Analyses of the garnets (Table 3) show molecular percentages in the range  $\text{Py}_{57-60}\text{Alm}_{23-28}\text{Spe}_{14-16}$ . The pyrope proportion is significantly higher than in amphibole and feldspar-bearing pyroxenites from the Anakies (Irving 1974a), Gloucester (Wilkinson 1974), Delegate (Lovering & White 1969, Irving 1974b) and Ruby Hill (Lovering 1964). There is a marked similarity to garnet compositions of feldspar-free pyroxenites from Delegate, Mt. Leura and Mt.

Shadwell (op. cit.), Table Cape (Sutherland 1979) and Salt Lake Crater, Oahu (Wilkinson 1976). Comparative analyses are plotted in Fig. 2. Mg content is lower than for most eclogite (griquaite) nodules from South African kimberlites (Nixon 1973) and Siberian kimberlites (Frantsesson 1969). No compositional differences were detected between large garnet grains and exsolved garnet lamellae within large clinopyroxenes.

Clinopyroxenes range from light grey-green and rich emerald green to black in hand specimens. Their composition varies from salite and augite to diopside (Table 2). Clinopyroxene compositions from garnet pyroxenite nodules near Delegate are closely comparable (Lovering & White 1969, Irving 1974b). Orthopyroxenes lie in the  $\text{En}_{72-90}$  range with alumina rising from 4% in the enstatites to around 8% in the bronzites. Except in garnet pyroxenites showing evidence of hybridisation, orthopyroxene is normally absent as distinct grains. Unaltered large clinopyroxenes have lamellae near bronzite in composition, although these are often replaced by garnet. Spinel is aluminous with most having compositions in the pleonastepicotite range. Their  $\text{Cr}_2\text{O}_3$  content (0.6 to 2.7%) is lower than that of typical kimberlitic spinels (Frantsesson 1969).

The presence of sporadic, patchy olivine around  $\text{Fo}_{85}$  and deep greenish-brown kaersutite in the hybridised metapyroxenites suggests a link with

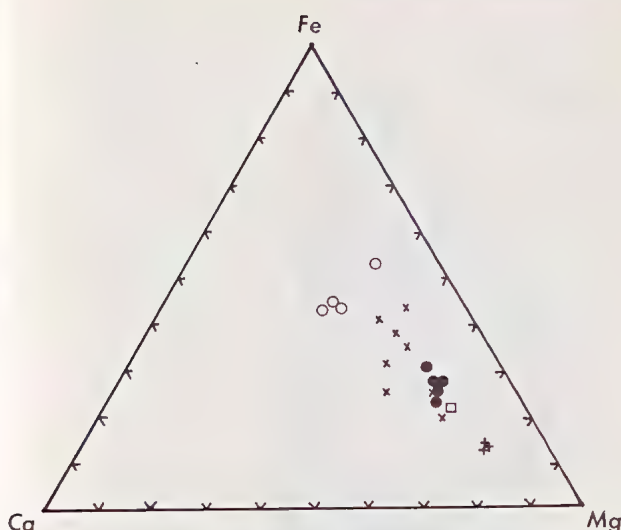


FIG. 2—GARNETS. Ternary diagram comparing ionic proportions of Ca, Mg, and Fe in garnets from Bullenmerri (black circles) with those from garnet lherzolite, Bow Hills, Tas (+) (F. L. Sutherland, unpubl. data); metapyroxenites, Salt Lake Crater, Oahu (square) (Wilkinson 1976); metapyroxenites and plagioclase pyroxenites, Delegate, N.S.W. (x) (Lovering & White 1976) and plagioclase pyroxenites, Gloucester, N.S.W. (o) (Wilkinson 1974).

the amphibole peridotites. Nodules showing the assemblage clinopyroxene + orthopyroxene + garnet + spinel + kaersutite + olivine show great variation in texture and composition, with even small specimens showing up to four distinct mineral assemblages (Bm 98). One of the rocks is garnet lherzolite which if found in isolation from the other rocks resembles higher pressure mantle material. Garnet compositions are identical to those in the olivine-free pyroxenites, which with their textural similarity suggest that the lherzolite is a hybrid phase resulting from mixing and exsolution reactions.

Banding is frequently seen in the metapyroxenites and boundaries are generally planar except for the hybridised varieties which show irregular contacts. Examples of textures and boundary relationships between rock types are given in Fig. 4.

Nodules comparable with the rare plagioclase-free spinel pyroxenites (websterites) of Delegate are much more common at Lakes Bullenmerri and Gnotuk, where plagioclase-bearing phases have not been found. Many examples show an exsolution reaction series yielding garnet as described by Green (1966), Lovering & White (1969) and Irving (1974b). This shows, under subsolidus cooling conditions, aluminous clinopyroxene exsolving garnet, some orthopyroxene and minor spinel. At the same time, spinel reacts with clinopyroxene to produce additional garnet. Fig. 5 gives examples

of textures displayed by nodules illustrating the clinopyroxene + spinel reactions. The spinel pyroxenite specimen Gn 36 is garnet-free with anhedral to subhedral black spinels up to 9 mm and greyish-green clinopyroxenes up to 40 mm long having thin orthopyroxene lamellae spaced at intervals of 0.05 to 1 mm. Minor granular orthopyroxene is present along irregular channels with fine spinel and granular clinopyroxene, perhaps reflecting zones of partial melting. This garnet-free stage is rare. Normally spinels have developed mantles of granular garnet which are clearly visible in Bm 67, although the orthopyroxene lamellae in the clinopyroxene often remain. Bm 62 shows spinels that have been largely expanded to form large, granular patches of garnet; whilst all the orthopyroxene lamellae are replaced by garnet in thin plates or blebs. Bm 57 shows granular garnet with little remaining of the former lamellar arrangement. Spinel is present only as isolated relict patches and there are sometimes small transparent brown grains of orthopyroxene.

Considerable experimental data exist for similar groups of nodules from Delegate (op. cit.) and Salt Lake Crater (Beeson & Jackson 1970). Such rocks have optimum conditions of formation in a dry state at a pressure range of 13 to 17 kb

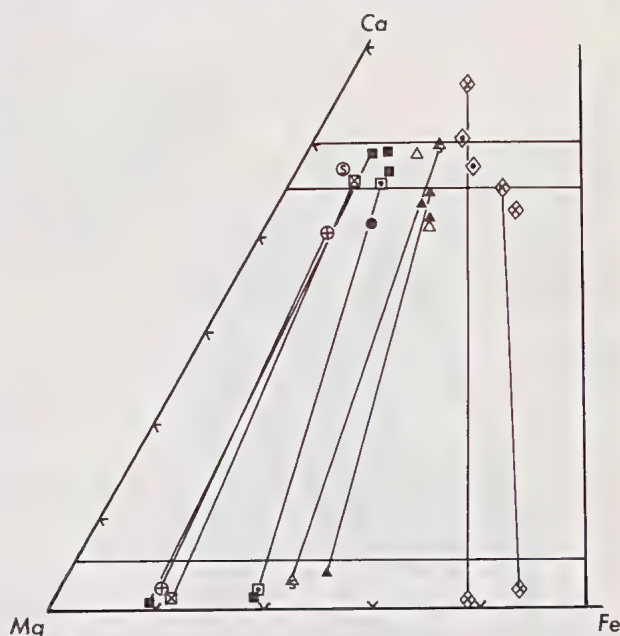
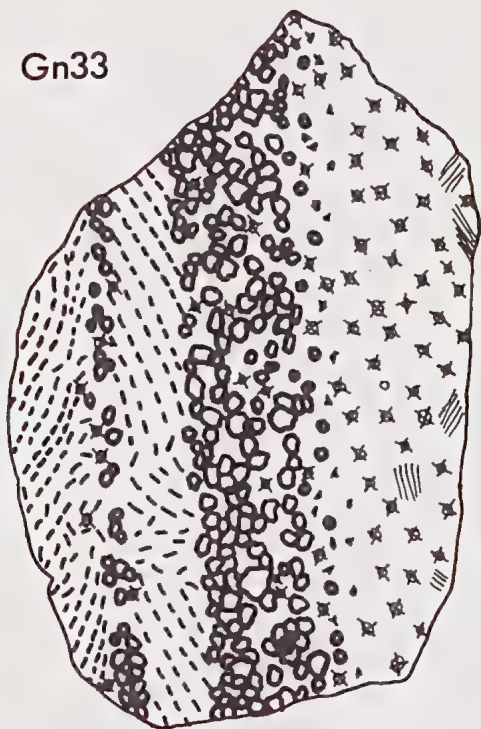


FIG. 3—PYROXENES. Ionic proportions of Ca, Mg, and Fe in pyroxenes from Bullenmerri (blacked-in symbols) compared with those from Mt. Shadwell (S) (Irving 1974a), Delegate (x), Bow Hills (+), Gloucester (\*) and Salt Lake Crater (plain). Circles are metaperidotites, squares represent metapyroxenites, triangles = cumulates and rhombs = plagioclase pyroxenites. Tie-lines indicate cpx-opx pairs.



Gn33



Gn40



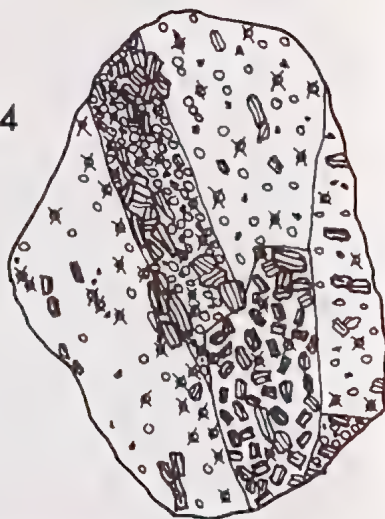
Bm68



Bm98



Bm114



Scale 5cm.

Grains/Lamellae  
Orthopyroxene

Bm114 only  
Clinopyroxene

Grains/Lamellae  
Garnet

Except Gn40 &  
Olivine Bm114

Kaersutite

Spinel

(representing depths of up to 70 km) and at temperatures of 1050 to 1100°C. As to their formation, Irving (1974b) and Beeson & Jackson (1970) favour a magmatic origin, perhaps as cumulates from local pockets of basaltic magma resulting from partial fusion of mantle peridotite, within the mantle. Re-equilibration under cooling conditions may have caused exsolution and recrystallisation with the resultant destruction of cumulus textures. The rocks now seen as nodules may represent a series of parents, liquids and residues connected with several episodes of basic magma generation. Green (1973) showed experimentally that melting garnet peridotite at 25 to 30 kb and 1200 to 1300°C with 2 to 7% water yields liquids of olivine basanite to nephelinite composition.

#### PERIDOTITES AND PYROXENITES

This is a varied group which includes dunites, harzburgites, wehrlites, websterites and clinopyroxenites which often show cumulate textures and sometimes banding of different rock types and grain-sizes. A few nodules contain xenoliths of metaperidotites and rarely metapyroxenites which are well rounded. Xenocrysts from the metamorphic groups may be present either singly or as schlieren. The wehrlites and websterites often have

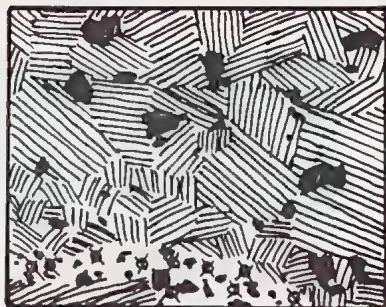
numerous 1 to 5 mm cavities which may be lined with small crystals of hornblende, biotite and rarely magnetite. The lack of metamorphic textures, an absence of Cr diopside and the presence of cavities make these rocks distinct from those of the metamorphic groups. Nodule types unknown elsewhere in Australia include the amphibole peridotite which shows randomly orientated euhedral olivines enclosed by poikiloblasts of deep brown pargasitic kaersutite over 10 cm diameter. Bm 42 has light brownish-green olivine crystals of up to 5 mm, showing multiple twinning and elongation along their c-axes. Other cumulates show olivine in clinopyroxene intercumulus and anhedral clinopyroxene in amphibole intercumulus. Olivine in cumulate nodules ranges from Fo<sub>65-82</sub>, orthopyroxene is En<sub>50-75</sub> and clinopyroxene ranges from diopsidic augite to salite; being richer in titania and FeO than the metaperidotite clinopyroxenes (Table 2). Boundaries between rock types within the peridotite-pyroxenite group are curved, irregular or gradational. They reflect in part, junctions between different intercumulus poikiloblast minerals. Nodules having intercumulus feldspars, represented at Mt. Franklin and the Anakies (Wass & Irving 1976) are absent. Most nodules belonging to this group had their origin in the lower crust. This is suggested by

Fig. 4—Petrographic Relationships in some Metapyroxenite and Metaperidotite Nodules

- Gn 33 Nodule shows three distinct metapyroxenite rock types arranged in five planar bands. The sequence from left to right (see Table 1) is B2-B1-B2-B1-B3. The B2 garnet pyroxenite shows relics of large pyroxene units which have had orthopyroxene lamellae replaced by garnet. The clinopyroxene has recrystallised to a granular aggregate. B1 is a typical garnet pyroxenite with approximately 55% of pinkish-red garnet in 2 to 5 mm grains. B3 is a hybridised pyroxenite which is garnet-free. A dark green, granular aggregate of aluminous diopsidic-augite (not marked), clear brown orthopyroxene grains and very rare olivine, contains rounded xenocrysts of clinopyroxene with orthopyroxene lamellae.
- Gn 40 A typical sharp contact between lherzolite (on right) and spinel pyroxenite is emphasised by a prominent zone of orthopyroxene. Large clinopyroxenes have orthopyroxene lamellae. Spinel, Cr diopside, enstatite and greenish-brown kaersutite occur interstitially to the clinopyroxene and also along a healed fracture running obliquely to the lherzolite contact.
- Bm 68 Diagram showing an advanced B2 garnet clinopyroxenite with relict clinopyroxene units having garnet lamellae. The pyroxene units are rounded and crumpled. Elsewhere in the specimen, clinopyroxene shows unaltered orthopyroxene lamellae, demonstrating that the mixing of material from different exsolution states occurred at least in part after the development of garnet. Dislocation zones intersecting the clinopyroxene units are lined with small blebs.
- Bm 98 This nodule shows significant features of a hybrid garnet pyroxenite with several petrographic types. Kaersutite, spinel and garnet occur in sporadic patches with scattered olivine. Except for the presence of garnet this mineral suite is characteristic of an amphibole lherzolite. Clinopyroxene (unmarked) is a deep green diopside with a lower Cr<sub>2</sub>O<sub>3</sub> content than for the Cr diopside common in the lherzolites.
- Bm 114 An oblique diagram of a complex kaersutite lherzolite block. Axes of the ovoid kaersutite patches give a marked lineation. Abundant Cr diopside forms a distinct band which includes large kaersutite patches. At the lower left, there is a face of finer granular kaersutite peridotite. This is part of the vein which cuts the general lineation and the Cr diopside band. A complex series of events is indicated by such nodules.

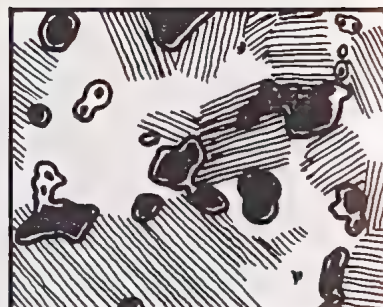


Gn36



Spinel pyroxenite of Primary Phase.

Bm 67



Spinel-garnet pyroxenite of early Garnet Exsolution Phase.

Bm62



Garnet-spinel pyroxenite of advanced Garnet Exsolution Phase.

Bm 57



Garnet Pyroxenite of fully exsolved Garnet Exsolution Phase.

Scale 3cm.

FIG. 5—Stages in the replacement of spinal and orthopyroxene lamellae by garnet. See Fig. 6 for key to symbols.

pyroxenes in comparable nodules from other localities which indicate a pressure range of 7 to 15 kb; e.g. Delegate (Lovering 1969).

#### HORNBLENDITES AND ESSEXITES

Ultramafic nodules having intrusive textures are common, especially along the south-eastern shores of Bullenmerri, where rounded hornblendite blocks weigh up to 12 kg. Hand specimens consist mainly of black titan-pargasitic kaersutite which is dark brown in thin section. Elongate interlocking crystals may exceed 5 cm and small vesicles are sometimes present. Ilmenite is a frequent accessory often as rough, irregular patches within the amphiboles. Deep brown biotite is sometimes abundant, but plagioclase is absent. The rocks are similar to the 'Iherzites' described as veins cutting peridotites in the French Pyrenees by Conquére (1971). An orange-red euhedral garnet crystal in a small cavity of specimen Bm 5 may be primary. Hornblendites from the Anakies have similar amphiboles, abundant garnet and plagioclase (Irving 1974a). The Bullenmerri blocks sometimes abound in xenolithic materials, producing com-

plex associations. As well as pyroxenites, modified garnet pyroxenites and small patches of granular olivine containing garnet occur. Hornblendites are frequently found as intersecting veins in Iherzolite nodules. Wass (1979) considers that these rocks represent magma that crystallised at upper mantle depths. Other veins in some cumulate pyroxenites may represent lower crustal intrusions, in part connected to the magmatic event that led to the maar-producing eruptions.

Coarse-grained mafic to felsic alkali gabbro or essexite blocks up to 2 m across are abundant along the south-eastern shores of Lake Bullenmerri. Although they occur on all the beaches, they are smaller and less common elsewhere. Lithologies vary from relatively fine grained rocks, resembling a theralite, to very coarse with acicular grey plagioclase crystals over 12 cm long. Thin hexagonal plates of ilmenite and acicular black titanaugite are conspicuous, producing an overall grey, decussate appearance. The petrology of these rocks is described by Grayson & Mahony (1910). The blocks are free from veining and xenoliths of any ultramafics. They may be

chemically related to the nepheline basanite magmas involved in the volcanism. The essexites were probably torn from alkaline intrusions in the upper crust during eruptions.

#### MEGACRYSTS

Anhedra of dark brown amphibole up to 4 cm long and related to the hornblendite nodules are abundant in the tuffs. A few crystals have parallel lines of 'pinholes', often having six-sided bores but no set orientation relative to their host's symmetry. Biotite or apatite may have occupied the holes. Rare fragments of clear anorthoclase come from rounded megacrysts up to 5 cm across. The amphiboles developed under hydrous conditions and may indicate that the initial maar eruptions were highly explosive (cf. Vinx & Jung 1977).

#### ROCK GROUP INTER-RELATIONSHIPS

Relationships within the metapyroxenite group and its contact with the metaperidotites, as observed in nodules are summarised in Fig. 6. This model represents a lower section of a metapyroxenite lenticle within the upper mantle peridotites.

The rarity of garnet pyroxenites in nodule suites as a whole, indicates that these lenticles are few and cover restricted areas. The spinel and orthopyroxene replacement series with garnet appears to occur away from peridotite contacts and is thus confined to thicker pyroxenite lenticles. Complex mixing textures appear as the result of subsequent disruptive, partial melting episodes which have resulted in the recrystallisation and Mg-depletion of the olivines and orthopyroxenes. These events may have been connected with the formation of amphibole peridotites, perhaps in association with shearing and diapirism in the upper mantle. The amphibole peridotites may be refractory products of local magma generation within the mantle, under hydrous conditions. These rocks are extremely rare elsewhere and they may be connected to the formation of the garnet metapyroxenites.

#### CONCLUSIONS

The localities described here provide important and abundant new material from which an evaluation of rock relationships can be made. The assemblage reflects a complex series of events that

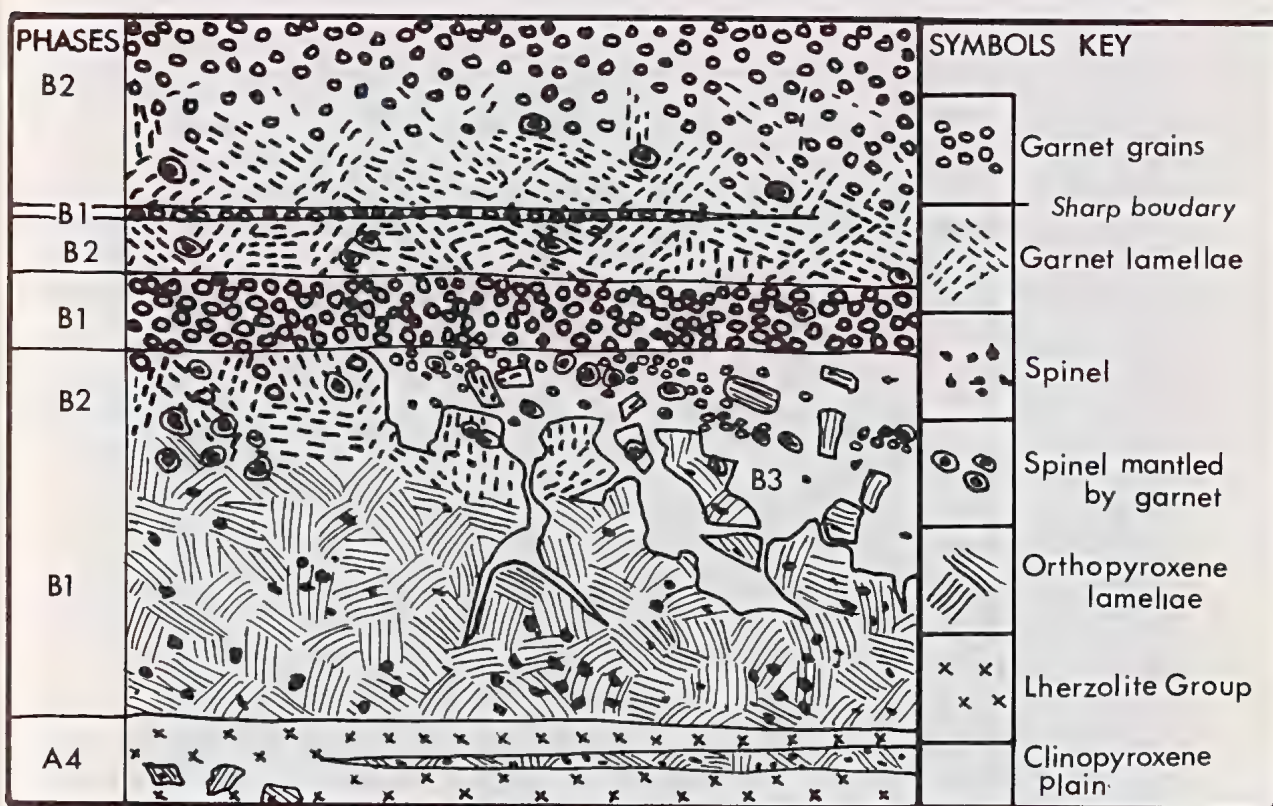


FIG. 6—Phase relationships in the Meta-pyroxenite group.



TABLE 4

ELECTRON MICROPROBE ANALYSES OF AMPHIBOLES AND SPINELS IN NODULES FROM BULLENMERRI AND GNUTUK

	AMPHIBOLES					SPINELS			
PHASE	A4	B3	B3 + C1	C1	C2	B1	B2	B3	B3 + C1
Specimen	Gn146	Bm106	Bm92	Bm108	Bm83	Gn141	Bm153	Bm55	Bm92
SiO <sub>2</sub>	42.95	42.45	42.55	41.84	41.11	0	0	.05	.01
TiO <sub>2</sub>	1.87	2.58	4.76	4.60	5.28	.14	.14	.07	1.12
Al <sub>2</sub> O <sub>3</sub>	15.20	14.87	14.17	14.85	14.06	62.13	62.53	61.75	55.30
FeO*	7.15	8.56	9.82	7.06	9.75	18.94	16.92	14.73	27.46
MnO	.11	.14	.05	.03	.08	.15	.15	.04	.07
MgO	15.99	14.73	12.73	14.83	13.10	17.46	18.06	20.28	15.03
CaO	10.98	10.69	10.17	10.50	10.10	.02	.02	0	.02
Na <sub>2</sub> O	3.43	2.87	2.83	3.11	2.86	.02	0	.05	.03
K <sub>2</sub> O	.26	1.69	1.49	1.52	2.28	0	0	.02	.01
Cr <sub>2</sub> O <sub>3</sub>	.08	.10	0	.12	.02	1.10	.90	2.69	.48
NiO	.12	.04	.08	0	.05	.26	.29	.27	.15
BaO	.05	0	0	0	0	0	.08	0	.01
Total	98.19	98.72	98.65	98.46	98.69	100.23	99.11	99.95	99.71
Ion%									
Mg	76.3	70.7	61.7	70.3	61.7	61.5	65.0	69.3	49.2
Fe	19.2	23.0	26.7	18.7	25.8	37.5	34.2	28.3	50.4
Ti	4.5	6.3	11.6	11.0	12.5	—	—	—	—
Cr	—	—	—	—	—	1.0	.08	2.4	0.4

\* Total iron as FeO (Fe<sup>2+</sup>).

have left textural records of shearing, hybridisation and partial melting. Certain significant events may be recognised in the nodules, although much clarification is needed, based on new data such as Nd-Sm ratios.

Important events included:

1. Formation or major reconstitution of the normal Cr diopside—spinel lherzolites between 2 and  $2.5 \times 10^9$  years ago is suggested on isotopic evidence (Cooper & Green 1969) from xenoliths at Mt. Leura, 1 km east of Lake Bullenmerri. Recrystallisation and partial melting episodes may have generated pyroxenite magmas that formed concordant bodies in the metaperidotites.

2. Pyroxenites and metaperidotites underwent a major thermal event around  $650 \times 10^6$  years ago (Burwell 1975). The resultant metapyroxenites may have yielded the garnet-bearing rocks by exsolution reactions. Shearing and hybridisation accompanied the generation of further pyroxenite melts at upper mantle levels, which intruded the metamorphic hosts, forming cross-cutting veins. Larger bodies of melt developed clinopyroxene and olivine cumulates.

3. Hornblendite magma intruded upper mantle rocks. The date of this event is conjectural, but one possibility is that it occurred during the Mesozoic. Hydrous magmas which could be

## PLATE 13

Fig. 1—Photomicrograph of spinel—garnet pyroxenite (AM6814) from Bullenmerri, showing large, primary spinels mantled by kelyphite alteration after garnet. Small blebs of garnet, exsolved from the pyroxenes, occur both interstitially to and along planes in clinopyroxenes.

High-pressure recrystallisation indicated by triple-point grain boundaries.

Fig. 2—Photomicrograph of garnet pyroxenite (AM6810) from Bullenmerri. Large, primary clinopyroxene with garnet lamellae exsolved after orthopyroxene, on left hand side. Large, ? primary garnet on lower right shows typical fracturing and black alteration rims. Also small interstitial grains of garnet amongst pyroxenes.

Both Plates approx. X 100. Photography by David Barnes.

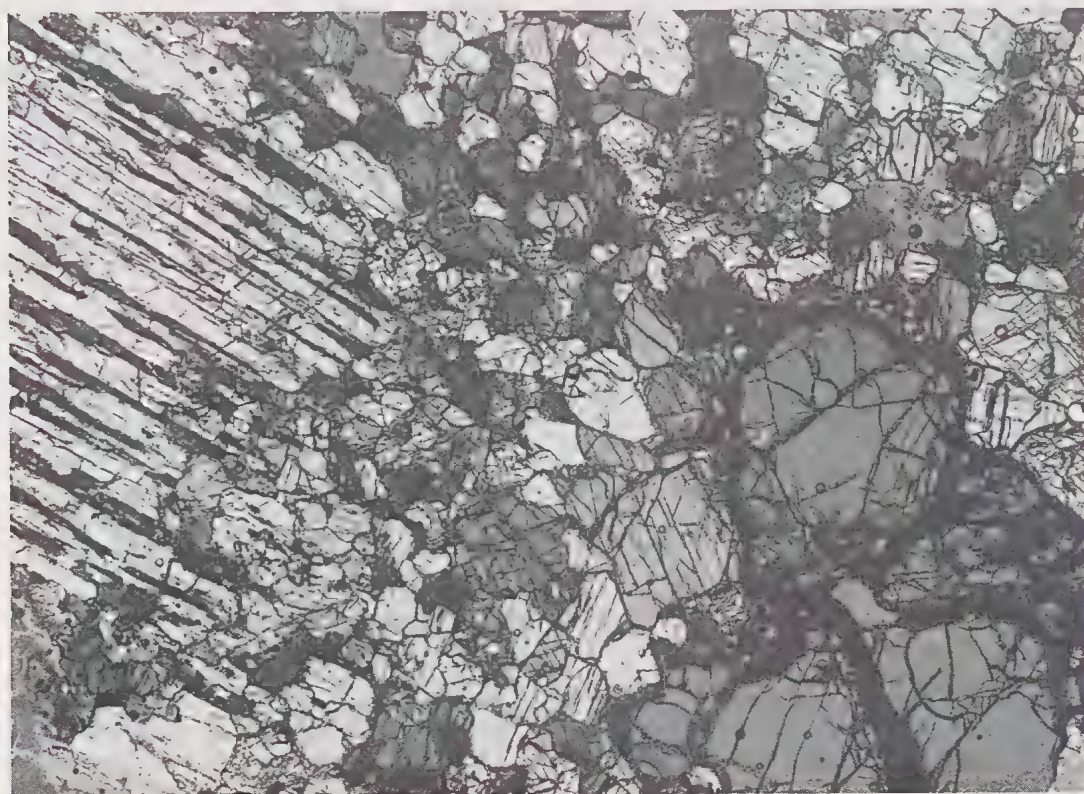


PLATE 13



related to the hornblendites produced volcanism in the Meredith area dated at  $163 \times 10^6$  years (Day *et al.* 1979) and kaersutite megacrysts occur in Jurassic volcanics of the Dundas Tableland (Fullarton & Tattam 1976).

4. The upper mantle was locally disrupted by magma diapirs which culminated in the Newer Volcanic Episode. Xenoliths were erupted with magma during the initial maar-producing activity at Lakes Bullenmerri and Gnotuk. Crustal blocks of essexite were included.

## ACKNOWLEDGEMENTS

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# *LINGULA* (LINGULIDAE, BRACHIOPODA) FROM THE LATE ARTINSKIAN (PERMIAN), CARNARVON BASIN, WESTERN AUSTRALIA

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**ABSTRACT:** *Lingula occidentaustralis* sp. nov. is described from the Early Permian Quinmanie Shale of the Carnarvon Basin, Western Australia. Faunal and lithological evidence indicates that the Quinmanie Shale was deposited in a very shallow marine (probably tidal flat) environment. Environmental constraints and global palaeogeography of Permian lingulids indicate that they were at times more tolerant of cooler water than living members of the family. Lingulids appear to have become more specialised and restricted ecologically during the late Palaeozoic.

## INTRODUCTION

Occurrence of the inarticulate brachiopod *Lingula* Bruguiere in the Permian succession of the Carnarvon Basin, Western Australia, was first mentioned by Teichert (1939, p. 6), but the species has never been figured or described. The comprehensive review of the family Lingulidae (Rowell 1965) and the recent ecological and taxonomic analysis of Triassic to Recent members of the family (Emig *et al.* 1978) provide an excellent framework for investigation of Palaeozoic lingulids. Taxonomy, ecology and global palaeogeography of Permian representatives of the family are reviewed below.

## WESTERN AUSTRALIAN MATERIAL

### STRATIGRAPHIC OCCURRENCE

In the Permian succession of the Carnarvon Basin *Lingula* is, apparently, restricted to the Quinmanie Shale (Teichert 1950, p. 1791) of the Minilya Sub-Group; Byro Group (Condon 1967, p. 163). Stratigraphic sections of the Quinmanie Shale have been provided by Teichert (1951, p. 117) and Condon (1954, pp. 75-78). The age of the Quinmanie Shale, from its stratigraphic position, is Late Baigendzinian (Late Artinskian, Early Permian). Correlations of the Carnarvon Basin Permian succession with other Australian Permian sequences are given by Dickins (1976). The substage name Baigendzinian is used in the sense of Waterhouse (1978) and Furnish (1973) to designate faunas of Late Artinskian and pre Kungurian (or pre Roadian = early Kungurian)

age. This usage, discussed fully by Waterhouse (1978), differs from earlier Soviet usage based on ammonoid studies which included the Kungurian within the Baigendzinian.

### ECOLOGY

Specimens of *Lingula* from the Quinmanie Shale, examined by the author, are preserved in rock samples ranging in lithology from siltstone to silty fine sandstone. Many specimens are isolated valves, indicating a degree of post-mortem transport, nevertheless, rare conjoined shells do occur in the collections. The associated fauna is moderately diverse; with eleven genera of molluscs (Dickins 1963) and other brachiopods, including such genera as *Neochonetes*, *Canocrinella*, *Spirelytha* and *Fusispirifer*.

Condon (1954, p. 78) considered the Quinmanie Shale to be a "typical" euxinic facies (pyritic black shale) deposited in a barred basin with restricted circulation, sentiments supported, in part, by Thomas (1958, p. 28).

The lithology of the Quinmanie Shale is typical of the sediment occupied by living lingulids (Chuang 1961, Paine 1970, Emig *et al.* 1978). Earlier investigators (e.g. Craig 1952) stressed a muddy environment whereas Emig *et al.* (1978) demonstrated that living lingulids show a clear preference for very fine sand. Chuang (1961) considered that the presence of organic matter in the sediment was to the advantage of lingulids, presumably to provide nutrients.

Since lingulids of the Quinmanie Shale occur as isolated valves, resulting faunal associations may



be a mixture of adjacent communities and it may be difficult to interpret the significance of such fossil assemblages (Craig 1952, p. 119). However, the few intact shells are important since Ferguson (1963, p. 672) stated "the possibility of intact shells of this inarticulate brachiopod being transported any appreciable distance is remote". Furthermore Bretsky (1969, p. 52) considered that the Linguloid-Molluscan assemblage, found in the nearest shore environment, was a stable association from Late Ordovician to Late Permian. His observations appear valid for the Quinannie Shale and presumably transport has not been significant. The Quinannie Shale contains a species of *Fusispirifer*, the population of which includes a high percentage (60%+) of juvenile individuals as determined from a study of the growth lines. Above and below the Quinannie Shale the Wandagee and Cundlego Formations represent well aerated sedimentary environments and each contains a diverse, articulate brachiopod dominated fauna. Populations of *Fusispirifer* in each unit consist of 25 and 30% juvenile individuals. The larger proportion of juvenile individuals of *Fusispirifer* in the Quinannie Shale appears abnormally high, suggesting a high mortality of juveniles due to unfavourable conditions (cf. discussions by Cloud 1948). A tidal flat environment, subjected to salinity variation such as would be caused by the periodic influx of fresh water which would kill off portion of the community, would be consistent with the high percentage of juvenile specimens of the *Fusispirifer* population and the ecology of most modern lingulids. This phenomenon has been well known for modern lingulid communities since Yatsu (1902, p. 66) quoted the observations of Hatta at Matsubate Inlet, Japan. The tolerance of *Lingula* to periods of lower salinity and confinement is well known, (Lum & Hammen 1962, Hammen *et al.* 1962) although little is known of such tolerance ranges (Ferguson 1963, p. 671).

#### TAXONOMY

Lingulids have maintained a remarkable uniformity and simplicity in shell form through time (Emig *et al.* 1978). The need for caution when delineating modern and fossil species on features such as shell outline and ontogenetic stages has been demonstrated by many authors (Kirkby 1860, Kawaguti 1942, Chuang 1961, 1962, Hammond & Kenchington 1978, Deleers & Pastiels 1952). Internal septa and muscle scars (both reflecting muscle attachment) are important in the classification of the group (Rowell 1965, Pajaud

1977, Emig 1977, 1979). The importance of muscle scars at the generic level is illustrated by *Apsilingula* Williams (1977).

#### SYSTEMATIC PALAEONTOLOGY

Order	LINGULIDA Waagen 1885
Superfamily	LINGULACEA Menke 1828
Family	LINGULIDAE Menke 1828

DIAGNOSIS: The diagnosis by Rowell (1965, p. H262) is accepted with the minor emendation of Williams (1977, p. 403) that the pseudointerarea is not always developed.

DISCUSSION: The Lingulidae has not been subdivided into subfamilies, but recent investigations (Emig *et al.* 1978, Pajaud 1977) indicate that the presence or absence of internal septa is a criterion for distinguishing relation-

#### EXPLANATION OF PLATE 14

All figures  $\times 3.5$ . All specimens whitened with ammonium chloride. All specimens, other than the Holotype, are Paratypes.

All specimens from the Quinannie Shale, Carnarvon Basin, Western Australia.

Figures 1-15. *Lingula occidentaustralis* sp. nov.

Fig. 1—Ventral valve, MUGD 5180

Fig. 2—Ventral valve, UWA 88098

Fig. 3—Dorsal valve, MUGD 5183

Fig. 4—Dorsal valve, MUGD 5179

Fig. 5—a, b, c. Ventral, profile and dorsal views of Holotype, MUGD 5181

Fig. 6—Dorsal valve, MUGD 5190

Fig. 7—Ventral valve?, MUGD 5182

Fig. 8—Dorsal valve, MUGD 5178

Fig. 9—Dorsal valve, MUGD 5177

Fig. 10—Dorsal valve, MUGD 5187

Fig. 11—Dorsal valve, MUGD 5185

Fig. 12—Dorsal valve, UWA 88099

Fig. 13—Dorsal valve, MUGD 5188

Fig. 14—Dorsal valve, MUGD 5184

Fig. 15—Dorsal valve?, MUGD 5189



PLATE 14



ships within the family. Since the occurrence of the genus *Glottidia* Dall in deposits of Tertiary age was reviewed by Chuang (1964), *Glottidia*-like genera have been shown to date back to the Early Triassic (Busnardo 1969 and Broglio-Loriga 1968 as discussed by Emig *et al.* 1978) and Late Permian (Rowell 1970, Newell & Kummel 1942). Several Carboniferous lingulids possess two septa in the ventral valve and one in the dorsal valve (Graham (1970). New genera of septate lingulids are indicated by variations in the type and arrangement of septa, for example a new Permian genus, with four septa in one valve, is indicated by *Lingula permiana* of Stauffer & Schroyer (1920). Illustrations of *Lingula credneri*, from the Lower Zechstein of the Fore Sudetic Monocline, Poland, given by Klapcinski (1971, p. 101, pl. 5, figs 3-6) indicate that some representatives of the *Lingula credneri* group possess internal, thin septa. It is considered that the septa bearing lingulids can be usefully separated into the Glottidiinae subfam. nov. diagnosed as: Lingulidae possessing septa in one or both valves. The subfamily Lingulinae Menke is restricted to those lingulids with weakly to very strongly impressed muscle scars and lacking internal septa.

#### Subfamily LINGULINAE Menke 1828

##### Genus LINGULA Bruguiere 1797

TYPE SPECIES: *Lingula anatina* Lamarck; I.C.Z.N. pending.

DIAGNOSIS: As given by Rowell (1965).

DISCUSSION: Rowell (1964, pp. 222-224) has discussed fully the need for the I.C.Z.N. to rule to preserve the stability of the generic name.

#### *Lingula occidentaustralis* sp. nov.

Pl. 14, figs 1-15

MATERIAL: A collection of 12 measured specimens and many fragments from locality W.L. 7-“*Lingula* Stage, Wandagee Series, Third *Lingula* Horizon Coolkilya Flat, 44 chains south of Garden Road, 231 Links past Station VIII”. Collector C. Teichert. Specimens housed in Geology Department, University of Melbourne (M.U.G.D.). A collection of 11 specimens from locality WL13 (U.W.A. Collection Number 27076), Locality unknown, “*Lingula* Zone” collected by C. Teichert 1940. Specimens housed in Department of Geology, University of Western Australia (U.W.A.).

DIAGNOSIS: Elongate species with lateral margins of shell almost straight and parallel in mature individuals. Muscle scars weakly impressed.

DESCRIPTION: Almost equivalve, biconvex shell. Convexity low; greatest posterior of midlength. Ventral valve slightly extended at umbo, slight development of ventral groove for passage of pedicle. Length almost twice width. Valves similar externally with fine sub-concentric growth lines. Interior of valves similar with extremely weakly impressed muscle scars. Dorsal valve interior with broad, linear, medianly placed, gently raised ridge. Ventral valve with similar platform, though

TABLE 1  
MEASUREMENTS OF *Lingula occidentaustralis*. sp. nov.

Specimen No.	Length	Maximum		Valve
		Width	Height	
MUGD 5178	14.8	8.9	1.7	Dorsal
MUGD 5179	13.5	7.7	1.3	Dorsal
MUGD 5180	12.5e	6.6	1.2	Ventral
MUGD 5181*	11.5e	6.5	2.8 (Thickness)	Complete Shell
MUGD 5182	—	7.8	1.7	Ventral?
MUGD 5183	14.2	7.7	1.3	Dorsal?
MUGD 5184	—	7.5	—	Dorsal
MUGD 5185	14.2	7.5	1.4	Dorsal
MUGD 5186	—	7.2	1.3	Dorsal
MUGD 5187	11.1	6.5	—	Dorsal
MUGD 5188	13.8	8.2	—	Dorsal
MUGD 5189	13.1	7.3	1.6	Dorsal
UWA 88098	13.6	7.7	1.4	Ventral
UWA 88099	12.4	7.2	1.2	Dorsal

e — estimate \* — holotype

narrower. Lateral margins of shell almost straight and parallel in larger specimens.

MEASUREMENTS: Measurements (in mm) are given in Table 1. Estimates of the shell length are made from a study of ontogeny of the species when the anterior margin of the shell is damaged.

DISCUSSION: *Lingula occidentaustralis* is similar to several other Permian lingulids, characterised by low, rounded umbones, straight, parallel sides to the shell in old age, and a low, broad median dorsal ridge. *Lingula arctica* Miloradovich (1936) from the early Permian (probably early Kungurian) of Novaya Zemlya (*non* L. *arctica* Wittenburg 1910, from the Lower Triassic of Spitzbergen) is similar, differing in being slightly more quadrate in outline and in possessing muscle scars that are more clearly impressed than those of the Western Australian species. Miloradovich's species was renamed *Lingula? miloradovichi* by Ifanova (1972). Her additional material from the Kungurian Vorkut Suite of the Pai-Khoy, while being close in outline to the Western Australian species possesses very strongly impressed muscle scars, recalling the genus *Apsilingula* Williams, 1977, although a muscle arrangement different to that of *Apsilingula* is indicated by Ifanova's figures (Ifanova, 1972, pl. 1, figs 1-7). *Lingula* cf. *arctica*: Harker & Thorsteinsson (1960, p. 49, pl. 15, fig. 12) is also close to the Western Australian species, with respect to shell outline, as is *L. freboldi* Gobbett (1964, p. 44, pl. 1, figs 1-2) from the Kungurian to Early Kazanian Upper Brachiopod Chert of Spitzbergen. Closer comparison of the Western Australian species with the Canadian and Spitzbergen species is regrettably impossible as these boreal occurrences are only documented by



one or two figures and internal muscle scars are poorly known. Comparison with *L. arctica* Miloradovich from the lower part of the Tumarin Suite, of possible early Kungurian age, from the Western and Northern Verchoyansk (Andrianov, 1966, p. 80) is impossible as the specimens are not figured. *Lingula taimyrensis* Einor (1946, p. 14, pl. 3, figs. 1-3; in the form *L. credneri* var. *taimyrensis*) from the Early Permian (Kungurian?) of the Taimyr Peninsula, is also similar to *L. occidentalis* in its subparallel lateral margins, low umbones and internal dorsal ridge, but again the boreal species is poorly known. *Lingula* has been widely recorded from the boreal region with all reports indicating species that are morphologically similar if not identical. The boreal species are also of similar early Kungurian age. The present record of a species of *Lingula* from the late Baigendzinian of Western Australia, that is morphologically similar to the boreal species, provides yet another example of the disjunct geographical distribution of Permian brachiopods that has been discussed by many authors (e.g. Ustritsky 1974).

The group of boreal lingulids outlined above is readily distinguished from most Carboniferous lingulids, which possess a more elliptical outline (Graham 1970, Kalashnikov 1970, Vangerow 1959) and the *L. credneri* group of Permian lingulids, which are much smaller in size and elliptical in outline (Alexandrowicz & Slupczynski 1970).

Asian and central north American lingulids attributed to *Lingula*, as summarised in Table 2, also appear elliptical in outline.

## PALAEOGEOGRAPHY AND PALAEOECOLOGY OF PERMIAN LINGULIDAE

### TAXONOMIC PROBLEMS

Generic placement of a lingulid species requires an accurate knowledge of internal structures, so generic assignment of many of the species in Table 2 is uncertain. I have restricted the review of Permian lingulids to reports accompanied by illustrations except for the Asian region where records of Permian lingulids are even more poorly documented than accounts for other regions. It is arguable that one or two occurrences listed in Table 2 are Late Carboniferous—as indicated.

### PALAEOECOLOGY

Ecological distribution of modern lingulids is well documented (Emig *et al.* 1978). They are adapted to shallow marine waters, subject to salinity fluctuations (Plaziat *et al.* 1978). They show a preference for a fine sandy substrate and are restricted by the 8°–10°C isotherms. Emig *et al.* (1978) considered these restrictive parameters constant from the Triassic to the Recent.

The lithology containing Permian forms has seldom been recorded in detail. However, where

available, most information indicates a fine sandy lithology (Rowell 1970, Alexandrowicz & Slupczynski 1970, Alexandrowicz & Jarosz 1971). Trechmann (1925, p. 538) recorded specimens of *L. credneri* from a thin bed of yellow dolomitic marl with sand and small rounded pebbles. Yochelson (1968) and Branson (1930) recorded specimens from shales of the Phosphoria Formation of Wyoming. Dickins & Shah (1977, p. 10) recorded lingulids and plant remains from ferruginous sandstones of Badhaura, India.

Several Permian lingulids lived in marine waters subject to fluctuations in salinity. "*Lingula*" *permiana* Stauffer & Schroyer (1920) from the Dunkard Series, Ohio occurs with a marginal marine assemblage. Miloradovich (1936, p. 78) writing of the Permian succession of the south island of Novaya Zemlya noted that "the petrographic character of rocks as well as numerous findings of *Lingula* . . . and plant remains permit to suppose . . . lateral marine deposits". Other records of Permian lingulids demonstrate more normal marine waters by an association of a diverse, articulate brachiopod dominated assemblage (Harker & Thorsteinsson 1960, pp. 10-12).

### PALAEOGEOGRAPHY AND PALAEOTEMPERATURE TOLERANCE

The provincialism observed in modern lingulids (Fig. 1) can be readily explained by taking into account the restriction to mobility imposed by the 8°–10°C isotherms. Lower temperatures appear to impose restrictions on the duration of the breeding season of modern lingulids (Chuang 1959). A striking departure from the latitudinal limitations of modern forms is evident in the figures of Permian lingulid distribution (Figs 2 & 3). Similar variations were noticed for Mesozoic and Tertiary members of the Lingulidae by Emig *et al.* (1978) who explained such changes as the result of periods of more equitable warm climates of global extent. Lingulids were widespread during the Permian (Figs 2 & 3) and several of the occurrences are in areas where the waters were cool as indicated by the rock record. While global fluctuations of temperature during the Permian are well known (see for example discussions in Frakes 1979, Waterhouse 1978, Waterhouse & Bonham-Carter 1975) and the alternation of cool and warm water faunas may occur within a single stratigraphic column, the inference is made that the various occurrences discussed below do indicate a tolerance by Permian lingulids of cooler water than is demonstrated by the group today. Never-



TABLE 2  
PERMIAN LINGULIDAE OF THE WORLD

SPECIES NAME	AUTHOR	LOCALITY	STRATIGRAPHIC HORIZON	AGE	GENERIC POSITION	ADDITIONAL REFERENCES and NOTES
<u>L. imbituensis</u>	Oliveira, 1930 (p.18; fig. top left of plate)	Santa Catharina, Brazil	Serie Itarare	Early Permian, Early Sakmarian	Type species of <u>Langella</u> Mendes 1961	Additional figures given by Lange, (1952, p.83; pl. 4, figs. 1-8)
<u>L. budoensis</u>	Martins, 1948 (p.237; figs. 1-2)	Rio Grande do Sul, Brazil	Serie Marica	Early Sakmarian	<u>Langella</u>	Synonymised with <u>L.</u> <u>imbituensis</u> by Lange (1952) and Mendes (1961)
<u>L. exporrecta</u>	Girty, 1910 (p.22; pl.1, fig.1)	Thomas Fork Wyoming U.S.A.	Phosphate Beds of Park City Formation	Artinskian- Kungurian	<u>Lingula</u>	
<u>L. carbonaria</u>	Girty, 1910 (non Shumard 1858?; pp.20- 22, pl.1, figs.2-5)	"	"	"	<u>Lingula</u>	<u>Lingula carbonaria</u> Shumard 1858, p.215 is a Pennsyl- vanian species
<u>L. sp. cf. carbonaria</u>	Yancey, 1978 (p.280, pl.1, fig.1)	Butte Mts Nevada, U.S.A.	Loray Formation	Kungurian	<u>Lingula</u>	
<u>Lingula sp.</u>	Cooper, 1957 (pl.1A, figs.1-3)	Oregon U.S.A.	Coyote Butte Formation	Kungurian	<u>Lingula</u>	
<u>L. permiana</u>	Stauffer and Schroyer 1920 (p.143; pl.9, figs.1-5)	Ohio U.S.A.	Dunkard Series (in black Shales of Washington Coal)	Early Permian	New genus of subfamily Glottidiinae	The presence of four septa in one valve indicates a new genus related to <u>Glottidia</u>
<u>L. borealis</u>	Newell and Kummell 1942 (p.953; pl.2, figs.1-4)	Wyoming Idaho Montana U.S.A.	Dinwoody Formation	Latest Permian	<u>Glottidia</u>	Relationship to <u>L. borealis</u> Bittner 1899 requires examination
<u>L. cf. arctica</u>	Harker and Thorsteinsson 1960 (p.49, pl.15, fig.12)	Grinnell Pen. Devon Island Arctic Canada	Assistance Formation	Kungurian	<u>Lingula</u>	H. and T. compared their specimens with <u>L. arctica</u> Miloradovich 1936, not <u>L.</u> <u>arctica</u> Wittenburg 1910 (p.37, pl.1, fig.7)
<u>L. ovata</u>	Dana, 1847 (p.152)	Black Head, Sydney Basin Australia	Sandstones of Gerrington Volcanics	Kazanian	<u>Lingula?</u>	Dana 1849, (text p.655-656, Atlas pl.2, fig.6)
<u>L. mytiloides</u> (non <u>L. mytiloides</u> Sowerby 1813)	Etheridge 1892 (p.264, pl.13, fig.19)	Spring Creek Cania, Bowen Basin. Australia	Yarrol Formation ?	Sakmarian ?	<u>Lingula</u>	Occurs with small Permian assemblage (Reid, 1930, p.60). Not mentioned by Dear (1968) Stratigraphic position unclear.
<u>L. occidentaustralis</u>	Herein	Carnarvon Basin, Western Australia	Quinnanie Shale	Late Artinskian, Baigendzhinian	<u>Lingula</u>	
<u>L. scrutata</u>	Reed, 1931 (p.39; pl.6, figs.6-7)	Salt Range Pakistan	Amb Formation	Artinskian	<u>Lingula?</u>	Rowell (1970, p.111 discusses stratigraphic position
<u>L. cf. borealis</u>	Rowell, 1970 (p.113; pl.1)	Salt Range Pakistan	Kathwai Member	Latest Permian	<u>Glottidia?</u>	The presence of internal septa indicates a member of the Glottidiinae
<u>L. aff. atra</u>	Schellwien, 1911 (p.141; pl.1, fig.4)	Sin-ho-yi China	?	Gzhelian or Asselian	<u>Lingula</u>	<u>L. atra</u> Herrick (1888, p.16, pl.10, fig.30) is an Early Carboniferous species
<u>Lingula sp.</u>	Wang, 1977 (p.399, figs. 1-2)	Weishan Lake Jiangso Province China	Shangshihezi Formation	Permian	<u>Lingula</u>	
<u>L. credneri</u>	Grabau, 1924 (p.497)	Ta-Lai-Pai Hung, Shui- Hsien China	Shansi Series	Late Permian, Kazanian	?	Not figured. <u>L. credneri</u> Geinitz is discussed below
<u>Lingula sp.</u>	Patte, 1935 (p.14-15, pl.1, fig.3)	Lon feng ya Kueichow, China	?	Latest Permian or Triassic	<u>Lingula</u>	
<u>Lingula sp.</u>	Masslenikov 1950 (p.102)	Sikhote Alin	Sandstone, Limestone Suite	Early Permian	-	Not figured

TABLE 2—(continued)

SPECIES	AUTHOR	LOCALITY	STRATIGRAPHIC HORIZON	AGE	GENERIC POSITION	ADDITIONAL REFERENCES and NOTES
<u>L. kolymensis</u>	Zavodovsky, 1968 (p. 70, pl. 30, fig. 3)	Kolyma Basin N.E. Siberia	Burgaliisk Suite	Asselian	<u>Lingula</u>	Also figured by Zavodovsky and Stepanov (1971, p. 70; pl. 1, figs. 2-3). May be middle to late Carbonifer- ous (Ustritsky and Muromtseva 1973, p. 117)
<u>L. taiymyrensis</u>	Einor, 1946 (p. 14; pl. 3, figs. 1-3)	Taimyr Peninsula	Lower Permian	Early Permian	<u>Lingula</u>	
<u>L. miloradovichii</u>	Ifanova, 1972 (p. 77; pl. 1 figs. 1-7)	Pai-Khoy Pechora Basin	Vorkut Suite	Kungurian	<u>Lingula</u>	Ustritsky 1960 (p. 94; pl. 1, figs. 1-2)
= <u>L. arctica</u>	Ustritsky, 1960	" "				
= <u>L. arctica</u> (non <u>L. arctica</u> Wittenburg, 1910)	Miloradovich, 1936	Mezhdusharsky Island Novaya Zemlya	Lower Permian	Early Permian	<u>Lingula</u>	Miloradovich 1936 (p. 37, pl. 2, fig. 4; pl. 3, figs. 1-3)
<u>L. praeorientalis</u>	Ifanova, 1972 (p. 79, pl. 1; figs. 8-9)	Pai Khoy	Gusinaya Suite	Early Artinskian	<u>Lingula</u>	
<u>L. hyberborea</u> = <u>L. credneri</u> Ustritsky 1960	Ifanova, 1972 (p. 80, pl. 1; figs. 10-16)	Pai Khoy	Vorkut Suite	Kungurian	Allied to <u>Glottidia</u> ?	Ifanova (p. 1; fig. 15) Indicates the presence of septa. Ustritsky 1960 (p. 96; pl. 1, figs. 3-6)
<u>L. vorkutana</u>	Ifanova, 1972 (p. 81; pl. 1, figs. 17-19)	Pai Khoy	Vorkut Suite	Kungurian	<u>Lingula</u>	
<u>L. rotundata</u>	Pogorevitch and Ifanova; Ifanova 1972 (p. 82; pl. 1, fig. 20)	Pai Khoy	Vorkut Suite	Kungurian	?	May not be a lingulid
<u>L. squamiformis</u> (non <u>L. squamiformis</u> Phillips, 1836)	Ustritsky and Chernyak 1963 (p. 67; pl. 1, fig. 1)	Taimyr Peninsula	Makarovsk Horizon	Late Permian	<u>Lingula</u>	<u>L. squamiformis</u> Phillips (1836, p. 221; pl. 11; fig. 14) Is Early Carboniferous in age
<u>Lingula orientalis</u>	Golovkinsky, 1868 (p. 360; pl. 2; figs. 11-12)	Schiya River	Kazanian	Kazanian	<u>Lingula</u>	
<u>Lingula lawrskii</u>	Necaev, 1894 (p. 139; pl. 6; figs. 11-12)	Kazan River	Kazanian	Kazanian	<u>Lingula</u>	
<u>Lingula</u> sp.	Grushenko, 1975 (pl. 25; figs. 2-3)	Donetz Basin	Nikitov and Kalitvenskaya suites	Asselian	<u>Lingula</u>	
<u>Lingula freboldi</u>	Gobbett, 1964 (p. 44, pl. 1; figs. 1-2)	Snitzbergen	Upper Brachiopod Chert	Kazanian	<u>Lingula</u>	
<u>Lingula credneri</u>	Geinitz, 1848 (p. 11; pl. 4; figs. 23-24)	Germanv	Zechstein (Kupferschiefer)	"	<u>Lingula</u>	Geinitz, 1861 (p. 106; pl. 8, fig. 1; pl. 15, figs. 12-13)
"	King, 1850 (p. 83; pl. 6, figs. 25-27) Davidson, 1858 (p. 51, pl. 4, figs. 30-31)	England "	Marl-Slate & Lower Magnesian Limestone	"	<u>Lingula</u>	
"	Alexandrowicz and Sluizynski 1970, (p. 700; pls. 1 and 2)	West Poland	Lower Zechstein	Kungurian	<u>Lingula</u>	
"	Alexandrowicz and Jarosz 1971 (figs. 1-6)	"	Sandstones			
"	Necaev, 1894 (p. 138; pl. 5; fig. 20)	Viatka River	Kazanian	Kazanian	<u>Lingula</u>	



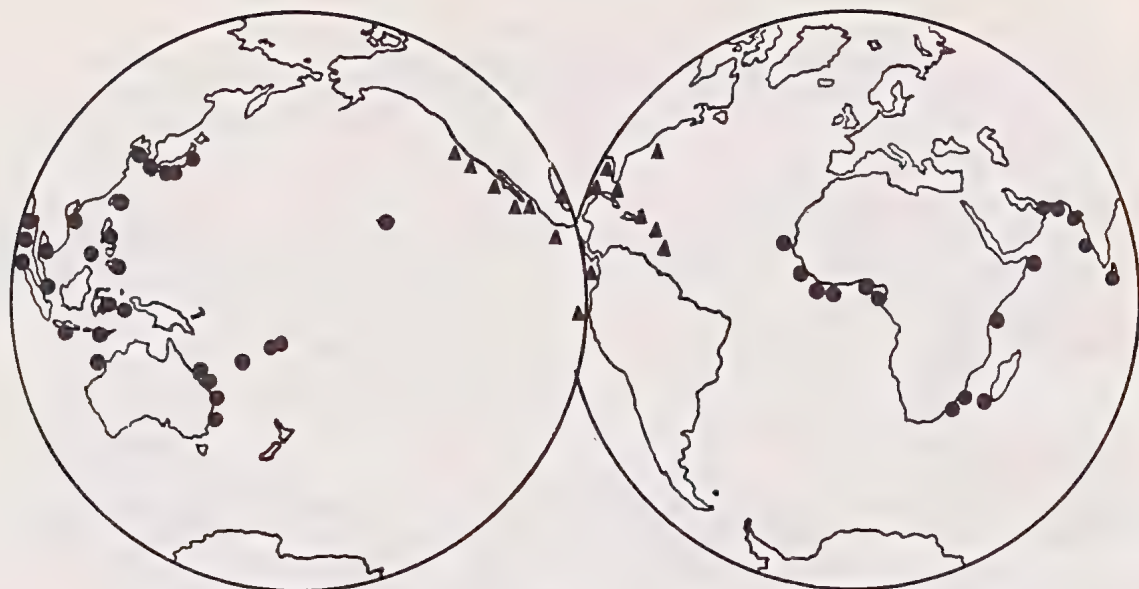


FIG. 1—The distribution of modern lingulids. • = *Lingula*; ▲ = *Glottidia*. Based on Zezina 1970, p. 155 and Emig *et al.* 1978, fig. 9.

theless in order to confirm this broader temperature tolerance detailed descriptions of the immediately associated stratigraphic sequence and lithology is required. Such information is invariably lacking. The South American occurrences are found in a stratigraphic interval at least in part of glaciogene origin—the Itarare Series, Santa Catarina, Brazil, (Ruedemann 1929). *Lingula? ovata* Dana (1847-1849) from the Sydney Basin, Eastern Australia occurs in the sandstones of the

Gerringong Volcanics and came from Black Head where the lithology is a sandstone with numerous glaciogenic dropstones. Boreal occurrences also indicate cool to cold water. Miloradovich (1936, p. 78) indicated a glaciogene component in the early Permian sequence of Novaya Zemlya. Other Boreal occurrences (e.g. Ifanova 1972, Einor 1946, Zavodovsky 1968) are with faunas of low diversity indicating cool to cold water (Waterhouse & Bonham-Carter 1975).

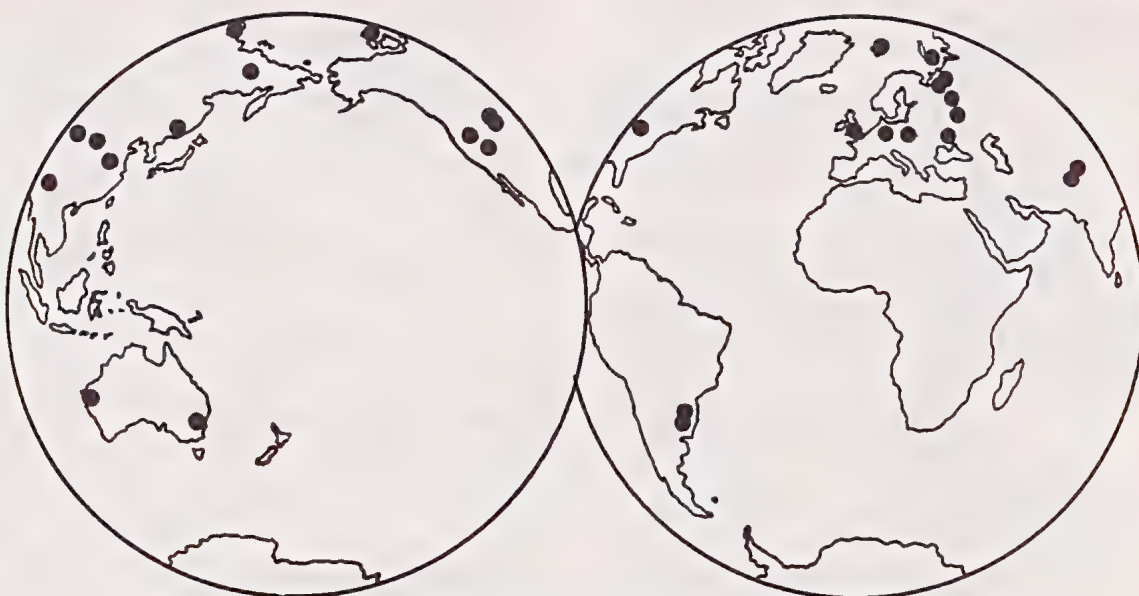


FIG. 2—The distribution of Permian lingulids on the modern globe.



FIG. 3—The distribution of Permian lingulids on a Permian reconstruction of the continents.

#### PROJECTION OF MAPS

Figures 1, 2 and 3 utilize the Lambert Equal-Area projections of Briden *et al.* (1974). Although a complete review of all reconstructions is beyond the scope of the present review, it should be noted that the Permian reconstruction of Briden *et al.* is only one of many available. Many palaeontologists have criticised this particular model as inconsistent when compared with the distributions of their faunas and floras (e.g. Hart 1974, using palynofloras; Waterhouse & Bonham-Carter 1975, using brachiopods; Ross 1979, using fusulinids and Ziegler *et al.* 1977, summarizing several groups). Palaeomagnetic data appear equivocal, with Japanese data indicating a Permian position at 13°N. (Minato & Fujiwara 1965) and/or an equatorial position (Hattori & Hirooka 1979) while Malaysian data indicate a Permian position at 15°N (McElhinny *et al.* 1974), unless the Asian plate (or plates) has rotated, as suggested by Hart (1974, p. 156). Other investigations, documenting stratigraphic or structural relationships, have indicated the close proximity of South East Asia to Gondwana (e.g. Ridd 1971, Acharyya 1979, Zonenshayn & Gorodnitsky 1977), unlike the Briden *et al.* model.

The Briden *et al.* (1974) and the Scotese *et al.* (1979) models are consistent with the recent review of the tectonics of China (Huang 1978), from a plate tectonics viewpoint.

#### CONCLUSIONS

The distribution of Permian lingulids indicates

an adaption to variable water chemistry and fine sandy sediment, similar to living forms. A wider tolerance of temperature variations, than that shown by modern species, is also indicated, with species inhabiting both warm (Asia) and cool (Eastern Australia, South America, Northern U.S.S.R. and Northern North America) water realms. Earlier in the Palaeozoic lingulids appear, at times, to have been further removed from their modern constraints, certainly occurring frequently in deeper water (Cherns 1979), or in a wide variety of sediment types such as muds, silts, ironstones, limestones and coarse sands (Graham 1970, p. 170). The above discussion indicates warnings against the assumption that a long-lived genus (or family) may occupy the ecological niche now that it has always occupied and that it may be still limited by the same set of ecological constraints. The family Lingulidae appears to have become more restricted (specialized?) through time; for example in relation to temperature since the Permian, and lithology since the Carboniferous.

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## ON THE NORTHWARD DRIFT OF THE AFRO-ARABIAN AND INDIAN PLATES

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**ABSTRACT:** Classical reconstructions of Wegener's Palaeozoic or Precambrian Pangaea, have shown a wide "Tethyan Gape" (proto-Tethys ocean) separating Laurasia in the north from Gondwanaland in the south during the early Palaeozoic. More recently detailed geological fieldwork in southern and central Asia has led to a variety of different configurations of continental plates in Palaeozoic reconstructions but most of these retain a fairly wide separation between the two major continents. The Afro-Arabian and Indian plates have been inferred as gradually approaching the Eurasian continent during the Mesozoic and reaching it somewhat later. This paper presents evidence to suggest that these plates were never far from the Eurasian continent and that a "Tethyan gape" did not exist in the Palaeozoic. Moreover, it lends weight to the theory of an expanding earth.

### INTRODUCTION

Classical reconstructions of Pangaea, exemplified by Dietz & Holden (1970) and then addressed by palaeontologists (Cowie 1971, Bulman 1971), suggested a Tethyan Ocean, a few thousand kilometres wide between Laurasia and Gondwanaland in the Palaeozoic. Early workers considered that the Afro-Arabian and Indian plates closed this ocean by northward drift that began in the Permian and ended in the Cretaceous. More recent work suggests that these events occurred later in the Mesozoic. An elongate WNW to ESE subduction zone along the southern edge of Laurasia has been assumed during these events and all the oceanic crust of the Tethyan ocean is assumed to have disappeared down this zone.

Finally the Afro-Arabian and Indian plates are believed to have collided with Laurasia and ophiolites are believed to mark the collision boundary at the surface although the plates underthrust beneath Laurasia in the Tertiary, uplifting central Asia to its present height.

### INDIAN-EURASIAN PLATE BOUNDARY

The presence of the *Glossopteris* flora and sections and other fossils typical of Gondwanaland during the Late Carboniferous and Permian in a 50 km belt from Longda, Selong, Qubu to Quzong north of the main Himalaya (Hsu 1976)

indicate that the Himalaya was then in the interior of Gondwanaland.

The supposed Indian-Eurasian plate boundary has been located along the upper Indus and Tsang-Pu River Valleys by recognition of a line of ophiolites (Yin & Guo 1976, Hsu 1976). It has been suggested (Bulman 1971, Takin 1972) that the Zagros Thrust north of the Persian Gulf was an extension of the same collision zone and marked the old Tethys Ocean but Stocklin (1974) has suggested that it is a comparatively young tectonic feature and the collision zone in that area was well to the north. Much has been written on the tectonics of southern Asia and it is not the intention to establish any new palaeogeography in this paper. Rather it is intended to add weight to Stocklin's (1974) arguments and to suggest that the wide Tethyan Ocean did not exist in the Early Palaeozoic and probably never existed at all.

### FAUNAL AND LITHOLOGICAL COMPARISON ACROSS THE BOUNDARY

#### CAMBRIAN FAUNAS OF IRAN (Fig. 2)

Much has now been written about the Cambrian faunas of Iran (King 1937, Kushan 1973, Fortey & Rushton 1976) and in the region of the Zagros Thrust line some Middle and Late Cambrian trilobite genera (e.g. *Iranoleesia* and *Chelid-*





FIG. 1—Reconstruction of Laurasia and Gondwanaland during the Early Cambrian (After Cowie 1971, fig. 4)

*onocephalus*) occur on both sides of the thrust line and nowhere else in the world. Most of the Cambrian trilobites of Iran both north and south of the thrust line are also to be found in China. If the Zagros thrust line was a collision boundary and represents a wide Palaeozoic ocean (Takin 1972, Bulman 1971) then the distribution of these faunas would be anomalous. The suggestions of Stocklin (1974) that the Zagros Thrust Line was not a collision boundary representing a wide Palaeozoic

ocean, accord far more with the palaeontological evidence.

CAMBRIAN SHELF SEQUENCES AND FAUNAS OF THE NORTHERN INDIAN PENINSULA AND CHINA (Fig. 3)

The Cambrian sequences in the Salt Range, Pakistan and in Yunnan, Southwest China correspond closely lithologically and contain the same sequence of fossils. Table 1 gives the correlated stratigraphic sequences for the two areas.

The Salt Pseudomorph Beds are composed of purple shales and sandstones and contain *Chittidilla plana* King and some brachiopods. The Douposi Formation well exposed in the Wuting and Luquan areas is also composed of purple sandy shales yielding many specimens of *Chittidilla* (Chang *et al.* 1980). The Magnesian Limestone (Schindewolf & Seilacher 1955) like the Lungwangmiao Formation is dolomite to dolomitic limestone.

The upper part of the *Neobolus* Shale contains the trilobites *Ptychoparia geei* King, *P. sakesarensis* King and *Redlichia noetlingi* (Redlich) and several different brachiopods including representatives of *Botsfordia* (Redlich 1901). The two species of *Ptychoparia* have been transferred to the late Early Cambrian Chinese genus *Yuehsiensziella* (Chang 1964). The Wulongjing Member of the Tsanglangpu Formation consists of green sandy shales yielding several species of *Redlichia* and inarticulate brachiopods. The Hongjingshao Member is composed of purple sandstones. The only mismatch is between the

TABLE 1

CAMBRIAN SECTIONS OF EASTERN YUNNAN, CHINA AND THE SALT RANGE, PAKISTAN

	Eastern Yunnan		Kusak, Salt Range
Early Middle Cambrian	Douposi Formation <i>Chittidilla</i> 50 m		Salt Pseudomorph Beds <i>Chittidilla</i> 85 m
	Lungwangmiao Fm. dolomite 100 m		Magnesian Limestone dolomite 75 m
Lower Cambrian	Tsanglangpu Formation	Wulongjing Member <i>Redlichia</i> 50 m	<i>Neobolus</i> Shales <i>Redlichia</i> 43 m
		Hongjingshao Mem. purple sandstone 100-150 m	Purple Sandstone 107 m
	Chiungchussu Fm.		Saline Series 500 m
	Meishucun Stage		?

Chiungchussu Formation, which does not contain evaporites, and the Saline Series of Pakistan. Otherwise these two sections exhibit an extremely close correlation on lithologies, thicknesses and fossil contents (Table 1).

In the Parahio Valley of Spiti in the Himalaya *Redlichia* is recorded in the middle Haimanta Series with *Oryctocephalus*, *Pagetia* and ptychoparioids in the upper part of the Series (Reed 1910). Similar faunas are found in the shelf to slope edge biofacies of Kweichow Province in southwestern China. Moreover *Tonkinella* and *Bailiella*, two distinctive trilobites are found in Kashmir (Reed 1934) and in China, the former in southeastern Yunnan, North China, and North America and the latter in central and northern China.

#### ORDOVICIAN TRILOBITE FAUNAS

Ordovician trilobite faunas described from Spiti

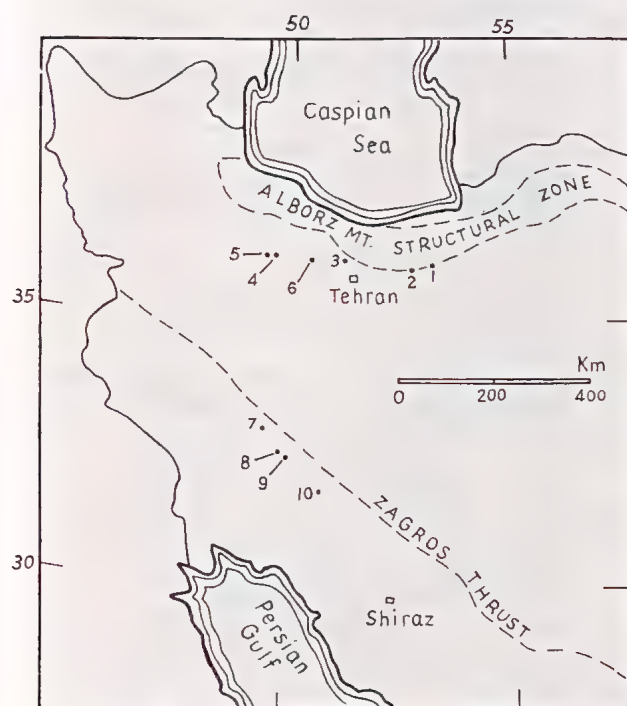


FIG. 2—Sketch-map of part of Iran.

- |                     |                  |
|---------------------|------------------|
| 1. Mila Kuh         | 6. Sanghabad     |
| 2. Shahmirzad       | 7. Chal-i-Sheh   |
| 3. Haanakdar        | 8. Darreh Shu    |
| 4. Abhar            | 9. Tang-i-Tehbud |
| 5. Quanli-Chapoghlu | 10. Ma'dan       |

*Chelidonocephalus alifrons* King is recorded from localities 1, 3, 4, 5, 7, 8, 9.

*Iranoleesia pisiformis* (King) is recorded from localities 1, 3, 4, 5, 10.

(After Fortey & Rushton, 1976, p. 322, fig. 12)



FIG. 3—Sketch map showing localities on the northern margin of the Indian block and its collision boundary with the Eurasian block (After Yeh, Liang, Shen & Xiang 1975, fig. 2).

and Niti in the central Himalaya (Reed 1912) contain the following genera in common with southwest China (Lu 1975)—*Basiliella*, *Illaenus*, *Amphilichas*, *Neseuretus*, *Sphaerexochus* and *Prosopiscus*. *Prosopiscus* is only known from Niti and northern Kweichow. According to Gortani (1935), *Illaenus spitiensis* and several species of brachiopods are common to the Himalaya and the Karakorum. The Ordovician fauna of the Karakorum is also closely related to those of southwestern China.

It should also be noted that Ordovician nautiloids described from Nyalam County, southern Tibet south of the Tsang-Pu River (Chen 1975) have several taxa in common with the faunas of the Yangtse Gorge section in China and other taxa found commonly in China.

#### CONCLUSIONS

Close similarities in the Cambrian and Ordovician endemic faunas of the northern margin of Gondwanaland and of China constitute sufficient evidence to seriously question or even deny separation by a vast ocean or deep water of any kind.

As a result of the study of the Cambrian stratigraphy and palaeogeography in Middle South Asia (Iran to North India), R. Wolfart and M. Kursten (1974) came to the conclusion that "According to the hypothesis of continental drift in the sense of Dietz & Holden (1970), for example, the Arabian Peninsula should have been situated in southern latitudes during the Cambrian separated from the Asian continent by a wide sea basin of the Tethys. The Cambrian geological conditions of Middle South Asia, on the contrary



point to the conclusion that Arabia, the Indian Peninsula and Asia geographically were immediate neighbours during that time." I agree with this conclusion.

Many modern reconstructions of the early Palaeozoic world differ in the relative situations of China, Chinese Tibet and India. For example Ziegler *et al.* (1977) placed Chinese Tibet on the equator contiguous with the rest of western China and directly opposite Australia across a seaway. Two years later the same group of authors Scotese *et al.* (1979) placed Chinese Tibet adjacent to India but very distant from China. In both cases Iran was split, presumably along the Zagros thrust line by a considerable distance. Smith, Briden & Drewry (1973) separated the Indian and Afro-Arabian plates from the rest of Asia although they were on the shores of the same rather narrow seaway. Jell (1974), also separated India, and Chinese Tibet-China by a considerable distance. These reconstructions as well as those of Cowie (1971), Bulman (1971) and Dietz and Holden (1970) already mentioned and others could be improved by consideration of the lithological and palaeontological data outlined above.

The discussion of faunas across the gape in Pangaea between Australia-Antarctica-India and southern Asia goes towards more concrete evidence for non-existence of this gape as propounded by Carey (1976) and used by him as evidence of a smaller radius Palaeozoic earth. While not making any comment here on the validity of the Expanding Earth Theory, Carey's claims that Tethys did not exist in the Palaeozoic appears valid in the detail as well as the general.

Although some individual faunal affinities may be explicable on the basis of other factors there is now so much evidence amassed that a wide Tethys Sea between the Indian, Afro-Arabian and Australian Plates on one hand and China on the other through much of the Palaeozoic seems quite impossible.

#### ACKNOWLEDGEMENTS

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# WETLANDS OF VICTORIA II. WETLANDS AND WATERBIRDS OF SOUTH GIPPSLAND

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**ABSTRACT:** Wetlands in South Gippsland were located and categorized using water regime and salinity; subcategories were determined using differences in vegetation. Six categories and twelve subcategories were recognized, but 90% of the total wetland area (about 76 000 ha) is intertidal flats. Only 3% of the total area is freshwater wetland and 75% of that is farm dams and water storages. Some 95% of the area of freshwater wetland has been destroyed since settlement.

Counts and observation of waterbirds showed that the most important wetlands in the study area are: (a) deep freshwater marshes on French Island and Phillip Island, where ibis, spoon-bill and cormorant breed; (b) the extensive salt pans in the east, which support large numbers of waterfowl and waders; and (c) the intertidal flats, which support most of the Victorian populations of Grey Plover, Mongolian Plover, Eastern Curlew, Whimbrel, Bar-tailed Godwit, Grey-tailed Tattler and Greenshank as well as large numbers of swans and ducks, herons and other wading birds. Examination of records of waterfowl banded in Victoria show that the proportion of bands returned, which have come from the study area, is much higher for Chestnut Teal than for Black Duck or Grey Teal. The salt pan and salt flat subcategories of semipermanent saline wetlands, and deep freshwater marshes in the western part are the only types of wetland adequately reserved in the Wildlife Reserves or National Parks systems.

The swamps at which ibis breed and the roosting and feeding areas of migratory waders must be protected from disturbance and alteration if these components of the waterbird resources of the study area are to be maintained.

## INTRODUCTION

Over much of Australia unpredictable rainfall prevents the regular formation of wetlands. Although many species of waterbird, which depend on wetlands for some part of their life cycle, are able to utilize these periodic habitats their survival ultimately depends on the presence of wetlands somewhere within their range at all times, particularly during widespread droughts (e.g. Frith 1967, Cowan 1973). During droughts wetlands are most likely to occur either where rainfall is most certain (i.e. the eastern and northern coastline and the south-west of Australia) or in marine and estuarine habitats. Thus wetlands in such regions are important in providing refuge for birds displaced by drought, as well as supporting locally breeding populations and non-breeding populations of migratory species. Surveys of wetlands in these regions of reliable rainfall have shown (e.g. Riggert 1966, Goodrick 1970, Corrick & Norman 1980) that

large areas of wetland have, and could still be, lost because of draining, clearing, cultivation and flood mitigation and irrigation works. As most of Victoria has reliable rainfall the area of each category of wetlands in the state and the extent to which each is used by waterbirds should be documented so that adequate wetlands can be conserved.

## STUDY AREA

The study area, approximately 10 000 km<sup>2</sup>, stretches from Merriman Creek in the east to the western edge of the catchment of Western Port and from the southern boundary of the La Trobe River catchment in the north to the coast. Phillip and French Islands in Western Port are also included (Fig. 1).

Human population is greatest in the outer suburban and developing industrial centres along the western boundary (e.g. Hastings — population 2000, Crib Point — 1900 and Ber-



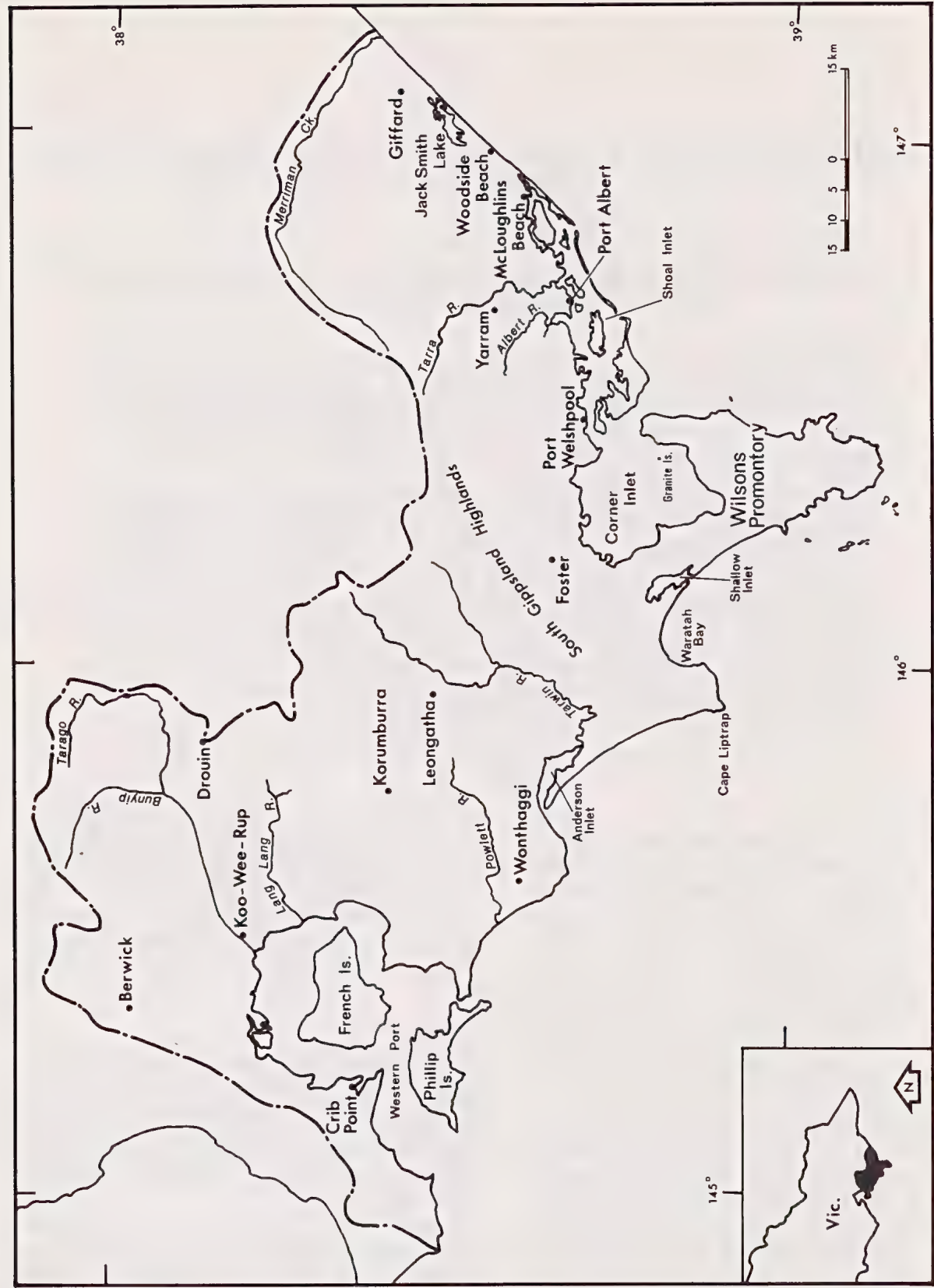


FIG. 1—The study area.

wick — 2000). Across the rest of the area population is based in rural towns (Drouin — 3000, Korumburra — 2900, Leongatha — 3400, Wonthaggi — 4400, and Yarram — 2000; estimated from population in 1971 from Bowden 1977). Many small coastal settlements, particularly on Phillip Island, attract large numbers of holiday makers and day-trippers during summer.

#### PHYSIOGRAPHY

The study area has been divided into many physiographic divisions (e.g. Hills 1964, Central Planning Authority 1968); however, in the following discussion divisions of similar topography have been grouped together into two main types: montane and lowland.

The Eastern Highlands and the South Gippsland Ranges, along the northern boundary of the study area, and the ranges of Wilsons Promontory in the south, reach 800 m. Elevation decreases both to the east and to the south where extensions of the ranges reach the coast near Phillip Island and at Cape Liptrap. In all, the ranges occupy some 40% of the study area.

Lowlands are close to sea level and generally have very low relief. South of Powlett River, in the eastern part of the study area and north of Wilsons Promontory, elevation is slightly higher and the relief increased by irregular sand deposits.

Coastal features include the systems of tidal channels, flats and small islands which have been enclosed by sand pits and off-shore sandbars (Jenkin 1968) at Anderson, Shallow and Shoal (i.e. between Port Welshpool and McLoughlin Beach) Inlets and the extensive intertidal flats, fringed in part by mangroves in Western Port and Corner Inlet. Non-tidal low-lying saline areas fed by minor streams have formed behind beach dunes toward the eastern boundary.

Extensive wetlands are restricted, by topography, to intertidal flats and neighbouring salt marshes, to non-tidal areas enclosed by beach sand deposits and to areas of low relief and poor drainage in the lowlands. Smaller wetlands have formed in dune swales where extensive sand deposits occur and in broader sections of river valleys.

#### CLIMATE

Rainfall is slightly higher in winter and spring than in summer and autumn and increases with altitude. Median (10 and 90 percentiles) rainfall is 1200-1600 mm (800-1200 and 1600-2400 mm) in the South Gippsland Ranges and the north west; 600-800 mm (600-800 and 800-1200 mm) about

Western Port; and 400-600 mm (400-600 and 600-800 mm) near Giffard in the east (Bureau of Meteorology 1968).

Droughts of 4 or more months have not been recorded at Warragul, which receives similar rainfall to most of the central part of the study area, but they are more frequent in the west (13% of years) and in the east (18%) (Central Planning Authority 1968).

Temperatures are modified by both altitude and proximity to the coast. In January mean maxima are 24-27°C inland and 21-24°C near the coast, mean minima are 10-13°C throughout. In winter mean maxima are 10-13°C coastal and 7-10°C inland, mean minima are 4-7 and 2-4°C respectively (Department of National Development 1966). Frosts become more frequent with increased altitude and distance from the coast; on the lowlands frosts may occur between mid April and September (Central Planning Authority 1968).

Run-off, after rain, depends on slope, soil and vegetation and evaporation rates. Evaporation rate, which averages 1010 mm p.a. along the coast and 760 mm p.a. in the ranges, is highest during summer (upto 160 mm in January) when it is 3 to 4 times the rainfall (Central Planning Authority 1968). Run-off is thus 25 - 50 mm p.a. near Seaspray, 50 - 120 mm p.a. in the west and 250 - 500 mm p.a. in the ranges (Department of National Development 1966).

#### HYDROLOGY

Streams in the study area are relatively small; the most important are the Tarwin River (gauged mean annual discharge  $284 \times 10^3$  ML from a catchment of 1070 km<sup>2</sup>, Bunyip River ( $153 \times 10^3$  ML from 660<sup>3</sup> km<sup>2</sup>) and Lang Lang River ( $72 \times 10^3$  ML from 300 km<sup>2</sup>). Flow in all streams is lowest during February and March and peaks during August. Exceptions are Merriman Creek, and Bunyip and Albert Rivers which have highest flows during September, October and June respectively (Bibra & Riggs 1971). These differences reflect local variation in the patterns of rainfall across the study area.

Seventeen urban water trusts and supply authorities operate in the study area; most involve only minor works. The largest storage, Tarago Reservoir, supplies water to the Mornington Peninsula and enables diversion of more than two-thirds of the mean annual flow in the Tarago River (Joseph 1975). Generally diversions for urban water and for irrigation of river flats along other streams only affect flows seriously during summer when flows are lowest.



## METHODS

## WETLAND DISTRIBUTION

Wetlands were located from aerial photographs (National Mapping, 1:85,000, flown 1967, 1968) from topographic maps and during ground surveys between October 1976 and February 1978. Water source and regime were determined for each wetland and its major plant communities were identified on the aerial photographs. The area of the wetland and vegetation types were calculated from planimeter measurements on the aerial photographs. All wetlands larger than 1.0 ha were included in this survey although some large farm dams constructed since 1968 may have been missed.

## WETLAND CLASSIFICATION

Distinctive vegetation communities were used to define subcategories within a system of wetland categories based on salinity and water regime. All categories and subcategories, other than intertidal flats, used in this report have been described previously (Corrick & Norman 1980), but all are summarized in Table 1. Intertidal flats are permanent saline wetlands which include both sandy areas usually devoid of vegetation and a variety of muddy substrates with a covering of marine halophytes (*Ruppia maritima*, *Zostera* sp. etc.) and algae. The flats are delimited by sandy beaches, mangroves and salt marshes and their extent and duration of exposure during each tidal cycle vary considerably with slope, variation in

TABLE 1  
CHARACTERISTIC WATER REGIME AND VEGETATION OF THE WETLAND CATEGORIES AND SUBCATEGORIES OF THE STUDY AREA.

Category	Depth (m)	Duration of inundation	Subcategory	Typical vegetation
Freshwater				
1 Flooded river flats	<2 m	<7 days	none	Determined by agricultural practice
3 Shallow marshes	<0.5 m	<6 months	.1 Herb-dominated	Annual moist soil and aquatic species
			.2 Sedge-dominated	<i>Lepidosperma longitudinale</i>
4 Deep marshes	<2 m	12 months	.1 Shrub-dominated	<i>Melaleuca ericifolia</i>
			.2 Reed-dominated	<i>Phragmites australis</i> and <i>Typha</i> spp.
			.4 Sedge-dominated	<i>Lepidosperma longitudinale</i>
			.5 Open water	Submerged aquatic species <sup>1</sup>
5 Permanent open water	>2 m	permanent	none	Submerged aquatic species, emergent species in the littoral zone <sup>2</sup>
Saltwater				
6 Semipermanent	<2 m	<8 months	.1 Salt pans	<i>Lepilaena</i> spp, <i>Ruppia maritima</i> <sup>3</sup>
			.2 Salt meadow	Halophytes with <i>Ruppia</i> & <i>Lepilaena</i> in shallows.
			.3 Salt flats	Dense ground cover of halophytes
7 Permanent	>0		.3 Intertidal flats	<i>Zostera</i> sp. various algae, none in places <sup>4</sup>

<sup>1</sup> Moist soil annuals in littoral zone.

<sup>2</sup> The distribution of aquatic species is limited by turbidity and emergent species by grazing and tramping by stock and by shore slope and aspect.

<sup>3</sup> No vegetation when dry.

<sup>4</sup> Excludes mangroves, most sand flats have no vegetation.

TABLE 2

THE NUMBER OF WETLANDS OF EACH CATEGORY AND THE NUMBER OF AREAS OF EACH WETLAND SUBCATEGORY IN EACH WETLAND SIZE RANGE (Category 1 River flats have been omitted).

Category/subcategory	Number of wetlands in the following size (ha) ranges				Total number	
	1-5	6-10	11-25	26-100	> 100	Subcategory Category
3 Shallow freshwater marsh						
.1 Herb-dominated	1					1
.2 Sedge-dominated	3					3
Number of wetlands	4					4
4 Deep freshwater marsh						
.1 Shrub-dominated	1	1	4	2		8
.2 Reed-dominated	1		3			4
.3 Sedge-dominated	22	5		4		31
.5 Open water	41	4	8	3		56
Number of wetlands	59	8	8	5		80
5 Permanent open freshwater	44	6		2	2	
Number of wetlands	44	6		2	2	54
6 Semipermanent saline						
.1 Salt pan	14	1	6	10	6	37
.2 Salt meadow	4	8	9	11	8	40
.3 Salt flat				1	2	3
Number of wetlands	17	9	11	13	10	60
7 Permanent saline						
.3 Intertidal mudflat					4	4
Number of wetlands					4	4
Total number of wetlands	124	23	19	20	16	202

tide height and the occurrence and direction of strong winds.

#### WATERBIRD DISTRIBUTION AND ABUNDANCE

The occurrence and abundance of all species of waterbirds was recorded. Large wetlands were visited several times during the study period. Intertidal areas about Corner and Shoal Inlets were surveyed on successive days (5-10 March and 24-29 November 1977) so that the number of migratory waders could be counted. The survey of Western Port was less thorough as it has been well documented by the Bird Observers Club (BOC) (see Loyn 1978). However, areas not included in the BOC surveys were visited and observations made of the distribution of birds at low tide. Ibis colonies and swamps on French Island were visited between 11 and 17 October 1977.

#### ANALYSIS OF WATERFOWL BANDING DATA

Waterfowl have been banded in Victoria mostly (81%) at the Division's Serendip Wildlife Research Station near Lara (38°01'S 144°25'E) (McNally &

Falconer 1953, Norman 1973). The number of recoveries of banded birds during hunting seasons between 1951 and 1977, is compared with those from elsewhere in Australia and the distribution of recoveries is plotted on a 10 minute grid of the study area.

## RESULTS

#### WETLAND DISTRIBUTION

Within the study area 202 wetlands totalling 75 900 ha were located. Tables 2 and 3 show distribution and area of each category and subcategory amongst various wetland size classes. More than half (124) of the wetlands are small (1-5 ha) amounting to only 0.4% of the total area. Fourteen wetlands are larger than 100 ha amounting to 98% of the total.

Freshwater wetlands form 3% (2270 ha) of the total but 75% of these and all the permanent open freshwater, is man-made dams and reservoirs. Permanent saline wetlands are all greater than 100 ha, and comprise 90% of wetland area. Distribu-



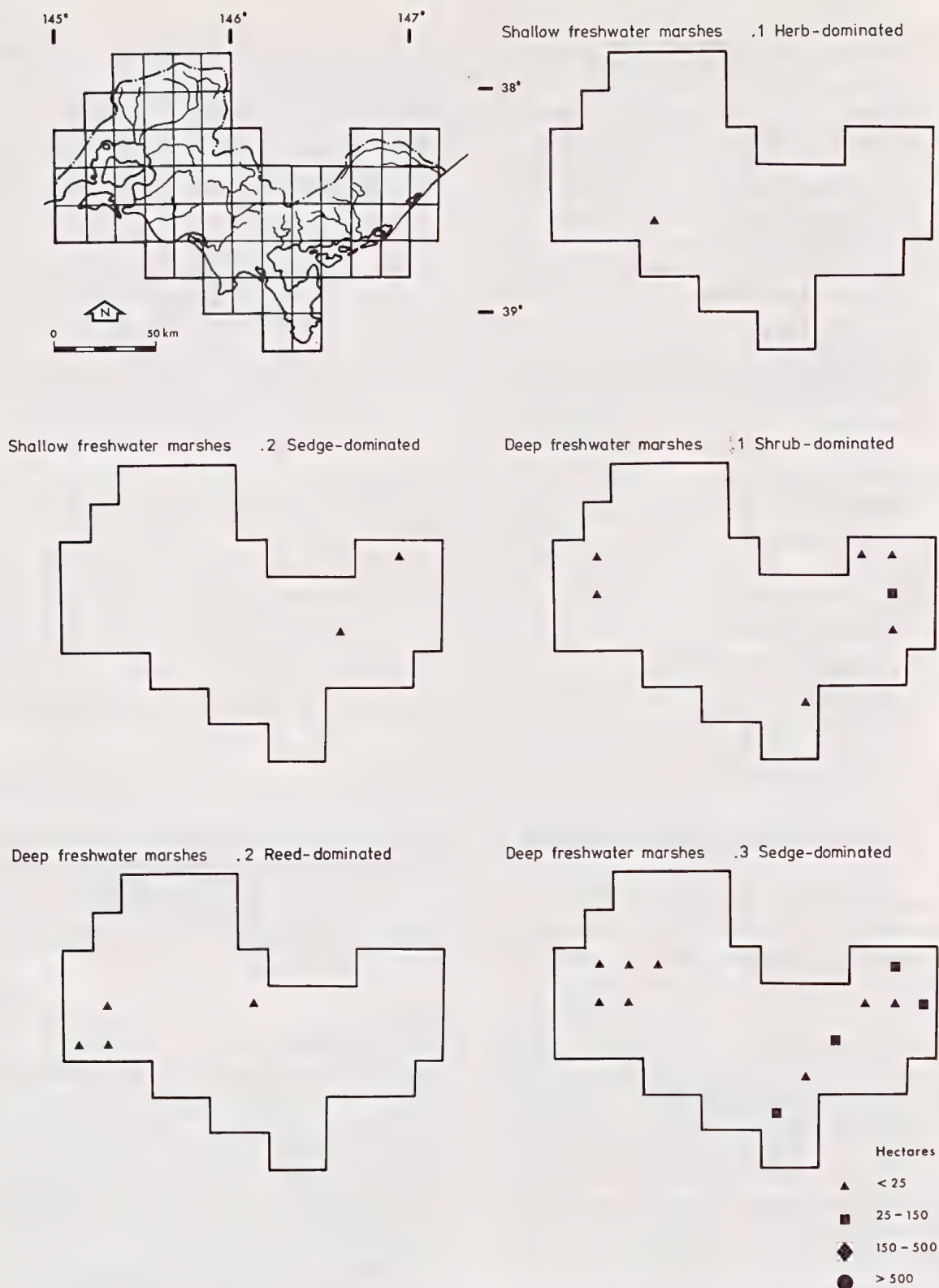
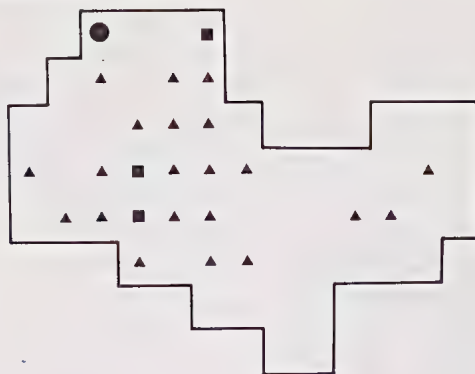


FIG. 2—The distribution (plotted on a 10' grid) of the area (ha) of each wetland category and subcategory of the study area.

Deep freshwater marshes .5 Open water



Permanent open freshwater



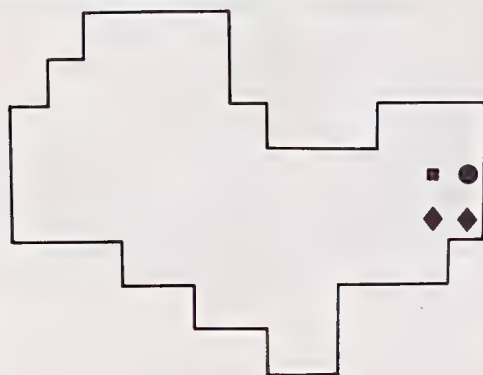
Semipermanent saline wetlands .1 Salt pans



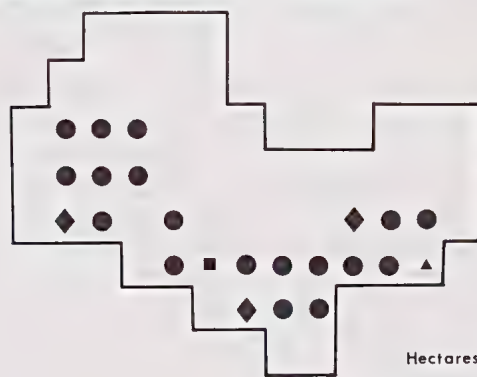
Semipermanent saline wetlands .2 Salt meadow



Semipermanent saline wetlands .3 Salt flats



Permanent saline wetlands .3 Intertidal flats



Hectares

- ▲ < 25
- 25 - 150
- ◆ 150 - 500
- > 500

FIG. 2— (continued)



TABLE 3  
AREA OF WETLAND CATEGORIES AND SUBCATEGORIES IN EACH WETLAND SIZE RANGE (Category 1 River flats have been omitted).

Category/subcategory	Area (ha) in wetlands of the following size ranges				Total area (ha)	
	1-5	6-10	11-25	26-100	>100	Subcategory Category
3 Shallow freshwater marsh						9
.1 Herb-dominated	3					3
.2 Sedge-dominated	6					6
4 Deep freshwater marsh						555
.1 Shrub-dominated	2	1	31	35		69
.2 Reed-dominated	1		24			25
.3 Sedge-dominated	53	33		156		242
.5 Open water	75	23	88	33		219
5 Permanent open water	87	43		87	1500	1720
6 Semipermanent saline						4960
.1 Salt pan	32	7	41	98	1030	1210
.2 Salt meadow	11	65	162	516	1930	2680
.3 Salt flat				16	1050	1070
7 Permanent saline						68700
.3 Intertidal mudflat					68700	68700
Total area	270	172	346	941	74200	75900

tion of the wetlands across the study area is shown in Figure 2.

Drained wetlands, located during this study, show that since European settlement only small areas of saltwater wetland have been lost (total 200 ha) because of harbour works, land reclamation and seawall and floodgate installation, and that the area of freshwater wetland has been drastically reduced. Some 39 000 ha have been eliminated mostly by the drainage of extensive swamps north of Western Port (Koo-Wee-Rup Swamp 22 200; Cardinia Swamp 14 700 and Yallock Swamp 2000 ha) and near Anderson Inlet (232 ha). A further unknown area has been destroyed or greatly modified by minor drain construction and cultivation along the Powlett (2200 ha) and Tarwin (1700 ha) river flats which are still flooded regularly. The habitats drained were most probably deep freshwater marshes (e.g. East 1935) although the extent of appropriate subcategories is impossible to determine. Of the natural freshwater wetland which once occurred in the study area 95% has been destroyed.

#### WATERBIRD DISTRIBUTION AND ABUNDANCE

Waterbirds recorded, wetland categories they utilize, and breeding and numerical notes are provided in Appendix 1 and Table 4. The distribution

of migratory waders recorded during the study is shown in Table 4. Seventy-three species of waterbird were recorded and 18 more have been recorded by other authors. The appendix shows that where large wetlands are absent a few species of waterbird (e.g. White-faced Heron, Black Duck, Masked Lapwing, ibis and Little Pied Cormorant) occur regularly, in small numbers, about farm dams along watercourses and on pasture. Concentrations of waterbirds mainly form on three habitats: deep freshwater marshes of French and Phillip Islands, where ibis, spoonbill and cormorant breed; salt pans and salt flats in the east that attract large numbers of waterfowl and waders; and extensive intertidal flats used by herons, ibis, gulls, terns, waterfowl and migratory waders.

#### WATERFOWL BANDING DATA

There are no clear differences in the distribution of recoveries of banded ducks during open seasons (Figure 3), although Grey Teal returns have come from a wider area (38 ten-minute grid squares) than Black Duck and Chestnut Teal (both 27 squares). Distribution of band recoveries appears to reflect practicability of hunting rather than distribution of wetland: most returns come from large semipermanent saline wetlands and from

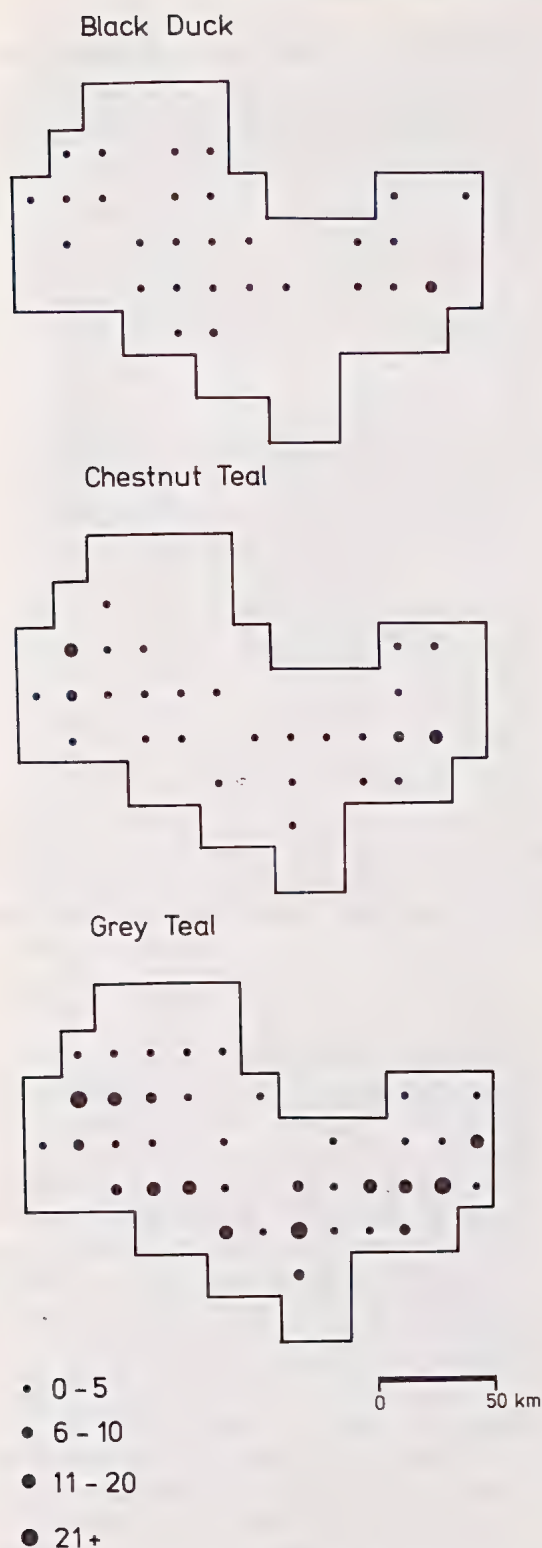


FIG. 3—The distribution (plotted on a 10' grid) of recoveries of banded Black Duck and Grey and Chestnut Teal shot during open seasons between 1953 and 1977.

small freshwater swamps close to intertidal areas rather than intertidal flats where lack of cover, tides and difficulty of movement make hunting impracticable. Recoveries from many inland squares, particularly in the South Gippsland Ranges, indicate that some birds are shot at small farm dams and along watercourses, both habitats too small to be included in this study.

The study area appears to be more important for Chestnut Teal than for other waterfowl which have been banded, because it accounts for 14% of all Victorian recoveries of Chestnut Teal but only 4% of Black Duck and Grey Teal recoveries.

## DISCUSSION

Destruction of extensive deep freshwater marshes, and of the water regime and vegetation along river flats has lowered populations of many waterbird species in the study area. Only a few species (e.g. Sacred Ibis, White-faced Heron) could have benefited from the pasture and agricultural land created by swamp drainage although some others (e.g. Black Duck, Little Pied Cormorant and Masked Lapwing) have become more widespread because of the numerous small farm dams created in previously forested area. Man-made wetlands do not compensate for the wetlands destroyed because they are not as extensive and they do not provide the same diverse habitats.

The area of wetland (75 900 ha) is similar to that about Gippsland Lakes (72 200 ha, Corrick & Norman 1980). However, there is much less deep freshwater marsh (1710 ha compared with 13 700 ha) and no large fresh or salt water lakes. Intertidal flats, absent about the Gippsland Lakes, are extensive.

The reduction in wetland area (35% of the total and up to 95% of freshwater wetland) has been more severe than about the Gippsland Lakes where 36% of the total and 34% of deep freshwater wetlands have been lost (Corrick & Norman 1980). The overall losses are also greater than found by comparable wetland surveys elsewhere in Australia (e.g. Goodrick 1970, Riggert 1966) where losses of 30-40% of the total and up to 60% of some categories have been recorded.

Where the only suitable habitats are small farm dams, streams, temporary pools or dry pasture, only small numbers of a few species of waterbirds occur regularly although small concentrations may form and remain on particularly suitable sites for some time. Most of the waterbird population is supported by wetlands of three categories (intertidal flats, semipermanent saline wetlands and deep freshwater marshes). Species (e.g. Hoary-



TABLE 4  
THE MAXIMUM NUMBERS OF MIGRATORY WADERS, RECORDED DURING THE SURVEY, ON THE LARGER AREAS OF SUITABLE HABITAT.

Vagrant species and Double-banded Plover (a winter migrant) are omitted. Where counts of Loyn (1978) differ markedly they are shown in brackets. The areas are (from west to east): 1 northern, 2 eastern, 3 southern Western Port; 4 Anderson Inlet; 5 Shallow Inlet; 6 southern and 7 northern Corner Inlet; 8 western and 9 eastern Shoal Inlet and 10 Jack Smith Lake.

	1	2	3	4	5	6	7	8	9	10
Grey Plover		2				50	60	520	320	
Lesser Golden Plover	5 (23)	30	40	8	20	4	3	10	170	26
Mongolian Plover	(1)	(3)	32	1					80	
Large Sand Plover		2							26	
Ruddy Turnstone	4	4	80				4		120	50
Eastern Curlew	300	600	450	500	550	460	600	1100	600	
Whimbrel		1	2 (20)			20	1	100	60	
Grey-tailed Tattler	20 (80)	12	29				60	30	70	
Greenshank	100	200	1	250	6	70	300	60	400	2
Terek Sandpiper	2	4		3				1	2	
Bar-tailed Godwit	34 (11)	34	225	20	4	800	1500	1200	3200	5
Red Knot		50 (30)				300	120	50	900	40
Great Knot							10		170	
Sharp-tailed Sandpiper		200 (500)	10 (254)	400				25	400	120
Red-necked Stint	1500 (2000)	2500 (5000)	1300 (3000)	2000	500	150	6200	1200	4000	3700
Curlew Sandpiper	1500 (3000)	2500	1400 (2000)	600	30	1600	5000	50	1500	80
Sanderling								4	60	

headed Grebe, Black Duck, Grey Teal, Musk Duck, Moorhen, Swamphehen and Coot), which are numerous on freshwater wetlands to the east (Corrick & Norman 1980) are consequently far less numerous in the study area because of the lack of freshwater wetlands. The remaining deep freshwater marshes thus provide important habitat for these species in the study area, particularly during summer and autumn when most other freshwater habitats are dry. Also, several of the deep freshwater marshes on French and Phillip Islands are the only places where colonially nesting species (Straw-necked and Sacred Ibis, Royal Spoonbill and Little Pied Cormorant) breed in the study area. The large semipermanent saline wetlands (Jack Smith Lake and Lake Denison) are important breeding sites for waterfowl if they contain water during winter and spring and they are also important feeding areas for large flocks of swan, duck (particularly Grey Teal) and migratory waders during summer, but their value as drought

refuge is low because they are usually dry during summer and autumn in years of below average rainfall when drought refuge habitat is most needed.

The most extensive wetlands and the most important for waterbirds in the study area are the intertidal flats which are feeding areas for herons, egrets, migratory waders, waterfowl, cormorants, gulls and terns. The number of birds using intertidal habitats is lowest during winter and spring when birds move to breeding areas or can use alternate feeding areas which become available in neighbouring pasture. During late spring and summer numbers then increase as temporary wetlands dry and migratory species return from breeding areas. Intertidal areas also provide drought refuge habitat for some species (e.g. Great Cormorant, Grey Teal and White Egret), irregular influxes of which occur particularly during summer, when the resulting flocks may remain from a few days to several months.

Migratory waders are easiest to count because they feed almost exclusively on intertidal flats and use traditional high tide roosting sites. When counts conducted during this study (Table 4) and by the BOC about Western Port (Loyn 1978) are compared with the few published observations elsewhere in Victoria they show that the study area supports the major part of the Victorian and probably south-eastern Australian (Thomas 1970) populations of several species.

Loyn (1978) indicated that in Western Port 6 species: Eastern Curlew, Whimbrel, Bar-tailed Godwit, Grey-tailed Tattler, Greenshank and Terek Sandpiper, '. . . were commoner than known normally elsewhere in Victoria'. However, each of these species (excluding Terek Sandpiper) is more abundant in Shoal and Corner Inlets than in Western Port. The number of Bar-tailed Godwit, in particular, is far higher than previously recorded elsewhere in Victoria (Loyn 1975, Smith 1966) or south eastern Tasmania (Thomas 1970). To these six species can be added Grey Plover which are more numerous in Shoal Inlet than on Mud Island and in Swan Bay which were the only places they were previously known to occur regularly (Wheeler 1960, Smith 1966, Klapste 1975). The study area also supports a large part of the known Victorian populations of Great Knot, Mongolian Plover and Sanderling, and the less abundant Large Sand Plover and Terek Sandpiper, which are all restricted to only a few sites elsewhere in Victoria (e.g. Smith 1966, Quinn 1967, Wheeler 1967, Cooper 1970, 1975, Klapste 1975, Loyn 1975, Carter 1976, Carter *et al.* 1976).

Intertidal flats and associated roosting sites in Shoal Inlet, northern Corner Inlet and Western Port are particularly important. The greatest threats to the extensive feeding areas would be large scale land reclamation, or widespread pollution. However, the number of places suitable for high tide roosting sites is limited and some roosts about Western Port are already disturbed frequently by fishermen and holiday makers. It is important that other roosts do not become exposed to similar disturbance because of improved access or development along the shore. Also some species, particularly Grey Plover, Whimbrel, Great Knot and Sanderling have habitat requirements restricting them to small areas of intertidal flats. This could make them vulnerable to minor changes in these preferred areas.

Wildlife Reserves and National Parks in the study area contain (a) a large proportion of the semipermanent saline wetland, and particularly salt pan, (Jack Smith Lake State Game Reserve),

(b) the swamps with breeding colonies on French and Phillip Island (French Island State Park and Rhyll Swamp) and (c) small areas of sedge dominated deep freshwater marshes and salt flats (Wilson's Promontory National Park). If the Land Conservation Council recommendations (Land Conservation Council 1977) are accepted many of the wader roosts and wader feeding areas in Western Port will become Wildlife Reserves or Wildlife Co-operative areas. Unfortunately feeding and roosting areas for waders in Shoal Inlet and northern Corner Inlet, which are important to several species (Great Knot, Grey Plover, Mongolian Plover and Whimbrel) which are not common in Western Port, remain unreserved although they are adjacent to Nooramunga Wildlife Reserve.

Wetlands of the study area support many water-bird species which are distributed either in small numbers over the many small wetlands or occur in much larger numbers on the few wetlands which contain breeding colonies, the few extensive semipermanent saline wetlands and on intertidal flats. Requirements of the species using these three important wetland categories, particularly the need for undisturbed breeding and roosting sites, must be met if the waterbird populations are to be maintained along with representative areas of the variety of wetland types which are present.

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## APPENDIX 1.

LIST OF WATERBIRDS RECORDED IN THE STUDY AREA WITH NOTES ON THEIR DISTRIBUTION AND ABUNDANCE. The 17 species of migratory waders listed in Table 4 are excluded. [Common names are from RAOU (1978)].

**GREAT CRESTED GREBE** Small groups occur irregularly, mainly about Corner and Shoal Inlets, also a permanent resident on some reservoirs (Davis & Reid 1974). Maximum seen 54 on Corner Inlet in October 1977.

**HOARY-HEADED GREBE** Usually in pairs but larger groups (up to 50) on inlets during autumn.

**AUSTRALASIAN GREBE** Freshwater only, the few records made reflect lack of suitable habitat.

**AUSTRALIAN PELICAN** Variable numbers in tidal inlets, larger farm dams and water storages. About 120 regularly roost in salt marshes on the northern shore of French Island where they have bred (Loyn 1975, 1978).  
**BLACK-FACED SHAG** Off-shore waters, single birds or small groups near the entrances to inlets except Corner Inlet where up to 300 roost on navigation beacons and Granite Island.

**GREAT CORMORANT** Usually single or a few birds on dams and rivers; but large concentrations occasionally for short periods on inlets (e.g. 4000 in Corner Inlet March 1977); has bred at Coolart Lagoon, 5 km south of Crib Point (Davis & Reid 1974).

**PIED CORMORANT** The least abundant cormorant, restricted to tidal inlets where groups form at high-tide roosts, groups of up to 140 in Western Port and to 30 in Corner Inlet. It has bred in the study area (Loyn 1975).

**LITTLE BLACK CORMORANT** Individuals and small parties throughout.

**LITTLE PIED CORMORANT** Widely distributed and abundant, breeds at Rhyll Swamp, Phillip Island; Coolart Lagoon, and on French Island.

**PACIFIC HERON** Pairs or single birds around dams and on pasture, unusual on intertidal flats.

**WHITE-FACED HERON** Abundant on all wetlands and pasture, numbers increase on tidal flats in late summer.

**CATTLE EGRET** Winter visitor to pasture, often roosts in trees over water. A flock of 170 near Wonthaggi, June 1977.

**GREAT EGRET** Singly or in parties throughout, numbers vary, particularly about mudflats e.g. 35 at the mouth of Bunyip River December 1976.

**LITTLE EGRET** Up to 9 near Port Albert but generally singly about inlets in the east. Few previous records in south east Victoria (Wheeler 1967).

**RUFous NIGHT HERON** Lower reaches of most rivers, Warneet and at Koo-Wee-Rup; Breeds near Hastings (Davis & Reid 1974).

**SACRED IBIS, STRAW-NECKED IBIS** Abundant on pastures throughout, the latter are rarely seen on intertidal flats. Both breed at Clump Lagoon (1000 nest October 1977), Heifer Swamp (280) and Little Heifer Swamp (300) on French Island. Moving to mudflats and mainland pasture to feed. Up to 400 pairs of Sacred Ibis nest at Coolart (Davis & Reid 1974) and both nest in Rhyll Swamp, Phillip Island. The breeding swamps and

trees in other swamps and farm dams are used as roosting places at night.

**ROYAL SPOONBILL** Breeds at Rhyll Swamp, Coolart Lagoon (Davis & Reid 1974) and at swamps on French Island. Flocks of up to 40 occur on all intertidal flats and move to neighbouring pasture during floods.

**YELLOW-BILLED SPOONBILL** Singly or in small groups on small swamps and farm dams throughout, rarely on mudflats.

**BLACK SWAN** On large farm dams and swamps throughout, often moving onto adjacent pasture to feed. Very large concentrations on intertidal flats of all inlets in summer e.g. Shallow Inlet 1500 January 1977, Corner Inlet 8000 March 1977, and Shoal Inlet 5500 November 1977. Many in these concentrations become flightless during moult.

**CAPE BARREN GOOSE** Small flocks on pasture at traditional sites (e.g. near Shallow Inlet) during summer. Occasionally appears elsewhere (Davis & Reid 1975, Brunt 1961). Roosts on small islands in Shallow Inlet (Cooper 1975).

**AUSTRALIAN SHELDUCK** Mainly on salt flats, salt pans and intertidal flats, and occasionally on pasture near farm dams.

**PACIFIC BLACK DUCK** Pairs and small parties on dams and swamps with some cover, large concentrations on large open wetlands (e.g. 600 Jack Smith Lake January 1977). Rarely on intertidal flats.

**GREY TEAL** Pairs and small parties throughout and large concentrations on intertidal flats and Jack Smith Lake.

**CHESTNUT TEAL** Pairs and small parties on large farm dams, and flocks to 300 on intertidal flats, particularly during summer and autumn.

**AUSTRALASIAN SHOVELER** Only small numbers recorded during the study. A pair with young on a farm dam on French Island, and many birds paired evidently in preparation for breeding at Jack Smith Lake in August 1978.

**PINK-EARED DUCK** Only at Jack Smith Lake (2 in July 1977 and 380 in August 1978).

**HARDHEAD** Mainly on open freshwater wetlands, occasionally on other habitats.

**MANED DUCK** Most common around farm dams in the east, small numbers near Foster and Wonthaggi.

**MUSK DUCK** Usually pairs or individuals on freshwater swamps and large farm dams, flocks do form (e.g. Drouin sewerage farm, 100 in July 1977; 80 in northern Western Port, May 1978; 260 in Western Port in June 1977 (Loyn & Bingham 1978).

**WHITE-BELLIED SEA EAGLE** Western Port (1 pair), McLoughlan Beach (1 pair) and Corner Inlet (1 pair). Three birds, including 1 juvenile, in Anderson Inlet in May 1977. Also around Wilsons Promontory (Cooper 1975).

**MARSH HARRIER** Pairs throughout the study area but most numerous on French Island.

**BUFF-BANDED RAIL** One in a roadside ditch near Anderson Inlet January 1977. See also (CCV 1974),



Wheeler (1967) and Davis & Reid (1975) for alternate assessments of status.

**PURPLE SWAMPHEN, DUSKY MOORHEN** A few scattered along the lower reaches of rivers, on large dams with scrub or reed cover and on freshwater wetlands. Rare on saline wetlands.

**EURASIAN COOT** Mainly large farm dams (flocks to 50) and reservoirs (flocks to 150) and Jack Smith Lake when full. Hardly ever on tidal inlets.

**PIED OYSTERCATCHER** Intertidal flats, breeding behind ocean beaches and on small islands; flocks to 80.

**SOOTY OYSTERCATCHER** Less widespread than Pied Oystercatcher but flocks form, particularly during summer and autumn, in southern Corner Inlet and Shoal Inlet (to 120).

**MASKED LAPWING** All wetlands and agricultural land, abundant.

**HOODED PLOVER** Mainly on ocean beaches, where it breeds, and occasionally in inlets and on salt pans close to the sea, small numbers only.

**DOUBLE-BANDED PLOVER** April to August in flocks of up to 200 on tidal flats and occasionally on short pasture and fallow away from water. Up to 1500 have been recorded in Western Port (Loyn 1978).

**RED-CAPPED PLOVER** Common on intertidal mud and sand flats and semipermanent saline wetlands.

**BLACK-FRONTED PLOVER** Occurs occasionally around large farm dams and freshwater swamps. Davis & Reid (1975) recorded it breeding.

**BLACK-WINGED STILT** Jack Smith Lake (January 1977) and salt marshes at Bunyip River mouth (October 1976); an infrequent visitor probably because of the lack of shallow freshwater swamps.

**RED-NECKED AVOCET** One Jack Smith Lake (July 1977); normal range is to the north and west of Melbourne.

**COMMON SANDPIPER** Less than 30 individuals in the study area, found separate from the other migratory waders, singly or in twos or threes, along the tidal reaches of creeks and rivers e.g. Tarwin and Tarra Rivers and about Western Port (Loyn 1975).

**LATHAM'S SNIPE** Rarely recorded in swampy drains and ditches close to the coast near Port Albert and Anderson Inlet, on salt flats on French Island and near the mouth of the Bunyip River. May also occur in small swampy areas of pasture—a habitat not included in the present study.

**BLACK-TAILED GODWIT** Single bird Corner Inlet March

1978, (see also CCV 1974, Simpson 1974, Loyn & Bingham 1978).

**SILVER GULL** Very abundant, in coastal areas, but occurs throughout particularly on rubbish tips and cultivated land. Nests on several islands in Shoal and Corner Inlets.

**PACIFIC GULL** Along the coast but numbers change seasonally as birds move to offshore islands to breed.

**GULL-BILLED TERN** Intertidal flats and channels at river mouths in Shoal (up to 30), Anderson (up to 8) and Corner Inlets (up to 30) and occasionally in Western Port (up to 9) (CCV 1974, Davis 1965, Loyn & Bingham 1978).

**CASPIAN TERN** Small numbers along the coast and throughout inlets e.g. Shoal and Corner Inlets (100), Anderson Inlet (10) and Western Port (60) Loyn & Bingham 1978). Nests on Ram Island (off southern French Island) and on islands in Shoal Inlet. Breeding birds easily disturbed by people and grazing stock.

**COMMON TERN** Summer visitor mainly to Shoal Inlet (140 Jan. 1977). Rare in inlets and along the coast west of Wilsons Promontory.

**LITTLE AND FAIRY TERN** Large flocks (to 170) in eclipse plumage (when they are inseparable) about Corner and Shoal Inlets between October and April. Adult Little Terns only recorded east of Corner Inlet. Fairy Terns nested on islands in Shoal Inlet and Western Port.

**CRESTED TERN** Common along the coast and in inlets. Flocks to 300 form on broad beaches and spits particularly when birds return from feeding off the coast. Several pairs nested on an island in Shoal Inlet.

Other species, that are irregular visitors, that have been recorded in the study area but not seen during this survey period are: Darter (Davis & Reid 1974, Wheeler 1967, Hyett & Gottsch 1966); Brown Bittern (Davis & Reid 1974, Cooper 1975, CCV 1974); Brolga (Wheeler 1967) Freckled Duck (Wheeler 1967); Blue-billed Duck—Woodside Beach September 1978 (Loyn 1978, Loyn & Bingham 1978); Lewin's Rail, Baillon's Crake, Australian Crake, Spotless Crake (Wheeler 1967, Davis & Reid 1974, 1975, CCV 1974, Cooper 1975); Painted Snipe (Wheeler 1967, CCV 1974, Davis & Reid 1975); Banded Lapwing (Loyn 1975, Davis & Reid 1975, Wheeler 1967); Red-Kneed Dotterel (CCV 1974, Loyn & Bingham 1976, Loyn 1978); Little Curlew (Cooper 1975, CCV 1974); Wood Sandpiper (Loyn 1978); Pectoral Sandpiper (CCV 1974); Oriental Pratincole (Loyn 1978); Whiskered Tern (Loyn 1978, Wheeler 1967, CCV 1974); White-winged Tern (Quinn 1966).

# NOTES ON *CALLIANASSA* (CRUSTACEA: THALASSINIDEA) IN WESTERN PORT, VICTORIA

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**ABSTRACT:** Populations of *Callianassa arenosa* Poore and *C. australiensis* (Dana) which co-occur in Western Port, Victoria, were sampled at monthly intervals over a period of one year. At the beginning (March 1976) and end (March 1977) of the study period *C. arenosa* was more abundant than *C. australiensis*, but in the middle *C. australiensis* was more abundant. *C. australiensis*, the larger species, provided the greater population biomass during most of the year. Both species showed a major peak in reproductive activity in spring. Only *C. arenosa* showed a marked summer peak in reproduction.

## INTRODUCTION

*Callianassa arenosa* Poore and *C. australiensis* (Dana) are abundant in intertidal and shallow subtidal, sandy sediments of Western Port, Victoria 145°20'E, 38°20'S (Coleman & Poore 1980. Hailstone & Stephenson (1961) described in detail the biology of *C. australiensis* from Queensland populations, but for Western Port populations information is more limited. Robertson (1977) showed the species to be important in the diet of the King George whiting, and briefly described reproductive patterns. Data for *C. arenosa* are restricted to brief descriptions of its abundance and sediment preferences in Port Phillip (Poore 1975) and Western Port (Coleman & Poore 1980).

To provide more specific information on the abundance, biomass and biology of *Callianassa* in Western Port, populations were sampled during 1976 and 1977.

## MATERIALS AND METHODS

Samples were taken monthly from March 1976 to March 1977 at a site in the north of Western Port where *C. arenosa* and *C. australiensis* co-occur (Fig. 1). Every month 24 samples, each consisting of sediment excavated to a depth of about 40 cm from within a 0.05 m<sup>2</sup> sampling frame, were taken. The samples were washed through a 2 mm mesh. *Callianassa* specimens were removed, kept in sea water for 24 hours and then frozen. The residue from sieving was preserved with 5% neutral formalin.

In the laboratory the *Callianassa* were identified into species, sexed, examined for eggs, measured along the length of the carapace and weighed. Sieve residues were sorted and *Callianassa* specimens found were treated as above except that dry weights were estimated from length-weight relationships of the unpreserved, freshly killed specimens.

## RESULTS

The relative abundances of the species changed considerably during the study period (Fig. 2). The population density of *C. arenosa* ranged from 25 to 109 per m<sup>2</sup> and this species was numerically dominant during March to May 1976, and during February and March 1977. The density of *C. australiensis* ranged from 11 to 303 per m<sup>2</sup> and this species was numerically dominant from June 1976 to January 1977. For most of the year *C. australiensis*, the larger species, provided the greater biomass (Fig. 2).

With *C. arenosa*, peaks of reproductive activity (as indicated by the proportion of ovigerous females) occurred during spring and summer (Fig. 3). The minimum carapace length at which ovigerous females were found was 4.5 mm. During spring only a small proportion of this size group was ovigerous but the majority were ovigerous during the summer.

Fluctuations in population density and biomass were correlated with reproductive activity. Peaks in biomass occurred when the proportion of



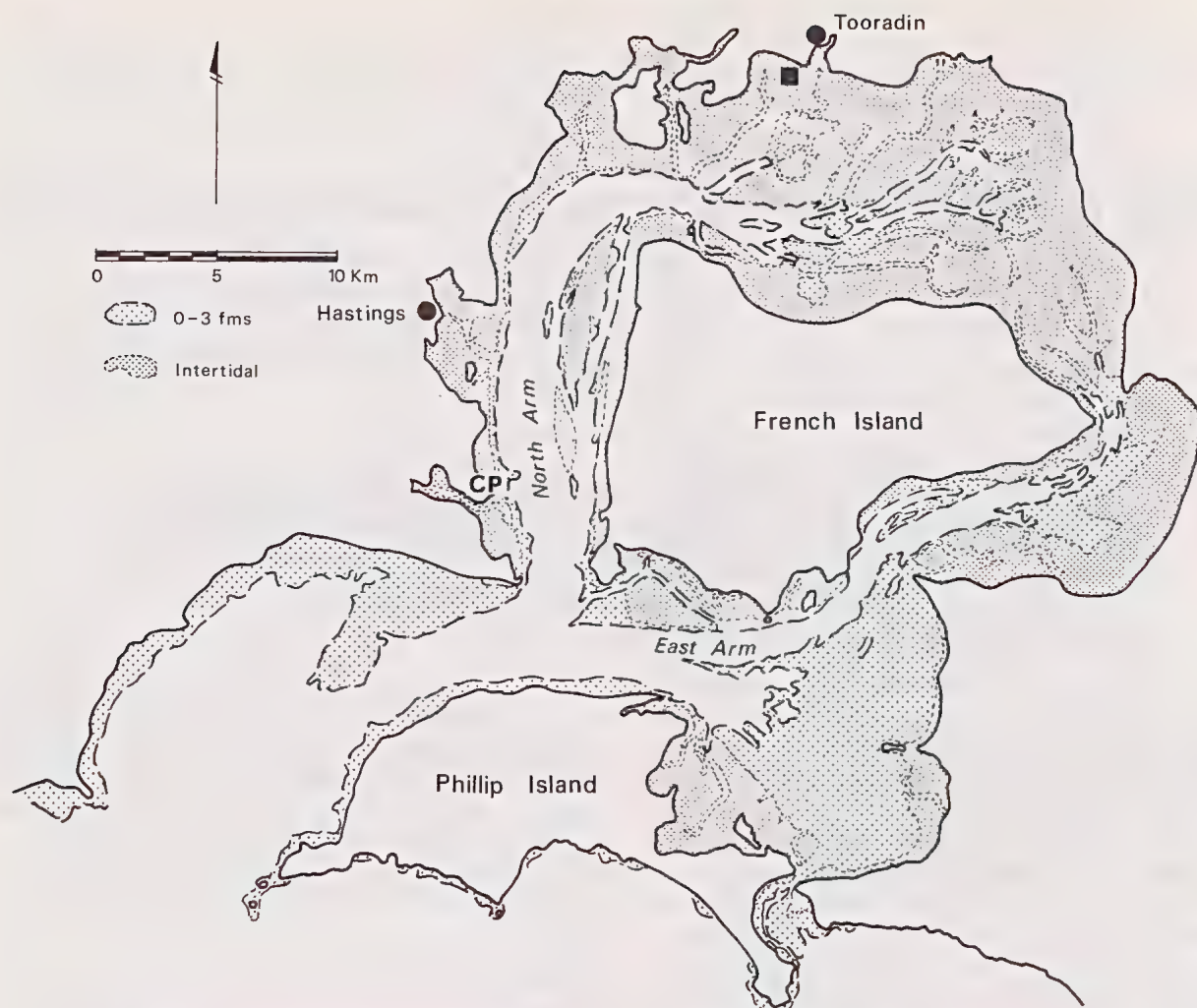


FIG. 1.—Map of Western Port ( $145^{\circ}20'E$   $38^{\circ}20'S$ ) showing sampling site of *Callianassa* (■). CP = Crib Point.

ovigerous females was greatest. Peaks in density, in October 1976 and during February and March 1977, shortly followed the appearance of ovigerous females, and samples in these months had a high proportion of small individuals (Fig. 4). The high proportion of small individuals in April and May 1976 is presumably from the summer spawning of 1975-76.

In *C. australiensis*, there was marked reproductive activity in September 1976, but only a very minor resurgence of reproduction in December 1976 (Fig. 3). Changes in population density and biomass were much more marked than for *C. arenosa* but were not clearly correlated with reproduction. At no time were small individuals dominant in the population. The great increase in abundance and biomass during October-December 1976, although following the period of

maximum reproductive activity, was due mainly to an increase in large, non-reproductive individuals. A minor peak in June had a similar cause (Fig. 5).

For both species, size frequency histograms gave no clear indication of year groups or of progression of modes that could be used to calculate growth rates. For *C. australiensis*, there was some indication of two size classes, indicative of two year groups, during October to December 1976, but for *C. arenosa* there was no indication of more than one size class at any time.

## DISCUSSION

The life history of *C. arenosa* has not previously been studied, but the present work shows it to be similar to that of other species of *Callianassa*.

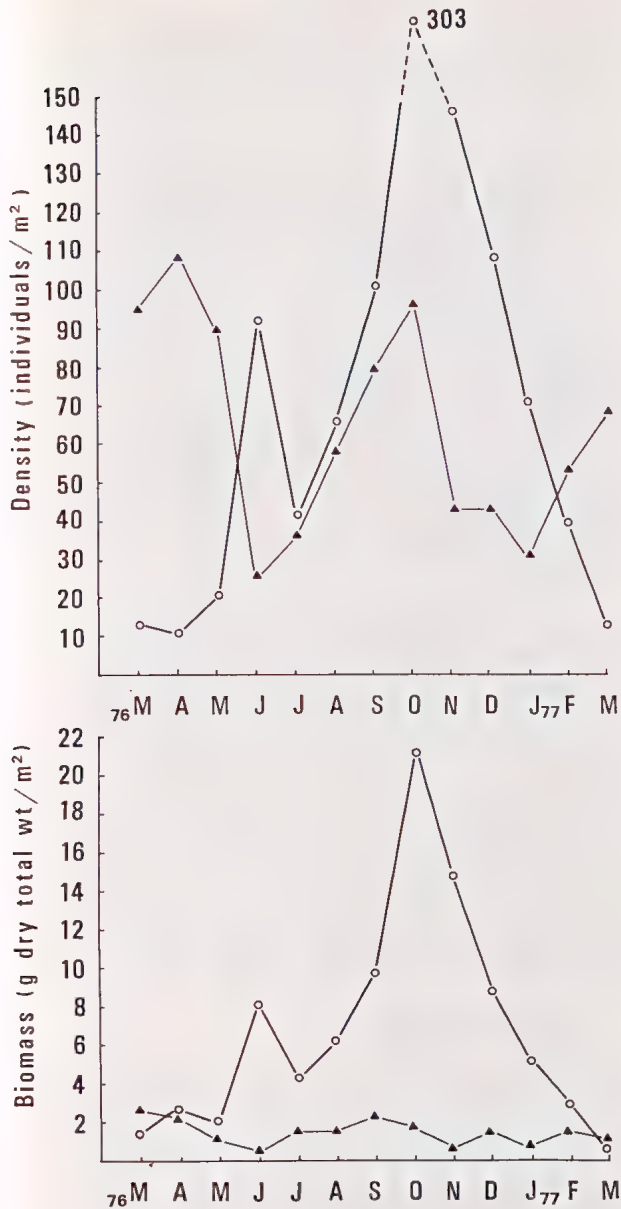


FIG. 2.—Monthly density and biomass for *Callianassa arenosa* (▲) and *C. australiensis* (○) from March 1976 to March 1977.

Monthly population densities were within values recorded for other species of *Callianassa* (Pohl 1946, Hailstone & Stephenson 1961, Poore 1975). The lack of progression of modes in size-frequency histograms has been previously reported for *C. australiensis*, and has been taken to indicate small-scale migration in and out of the population (Hailstone & Stephenson 1961). An extended reproductive period with one or two peaks of activity has been reported for the American *C. californiensis* (MacGinitie 1934), for *C.*

*australiensis* in Queensland (Hailstone & Stephenson 1961) and Victoria (Robertson 1977), and for the New Zealand *C. filholi* (Devine 1966).

The proportion of large ovigerous *C. arenosa* was similar in spring and summer, but only a few of the smallest individuals capable of reproduction were ovigerous in spring. Perhaps for small individuals at this time somatic growth is more important than the production of gametes and takes place at the expense of the latter. A similar situa-

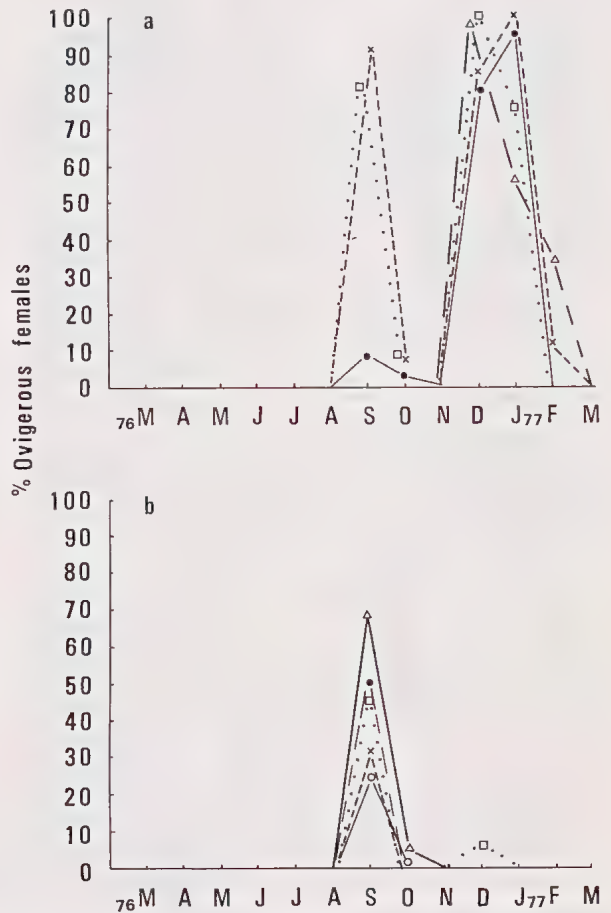


FIG. 3.—Ovigerous females in monthly samples of *Callianassa* from March 1976 to March 1977.

a. *C. arenosa*

- — — — ● 4-5 mm carapace length;
- × — — — × 5-6 mm carapace length;
- — — — □ 6-7 mm carapace length;
- △ — — — △ 7-8 mm carapace length.

b. *C. australiensis*

- — — — ● 5-6 mm carapace length;
- × — — — × 6-7 mm carapace length;
- — — — □ 7-8 mm carapace length;
- △ — — — △ 8-9 mm carapace length;
- — — — ○ 9-10 mm carapace length.



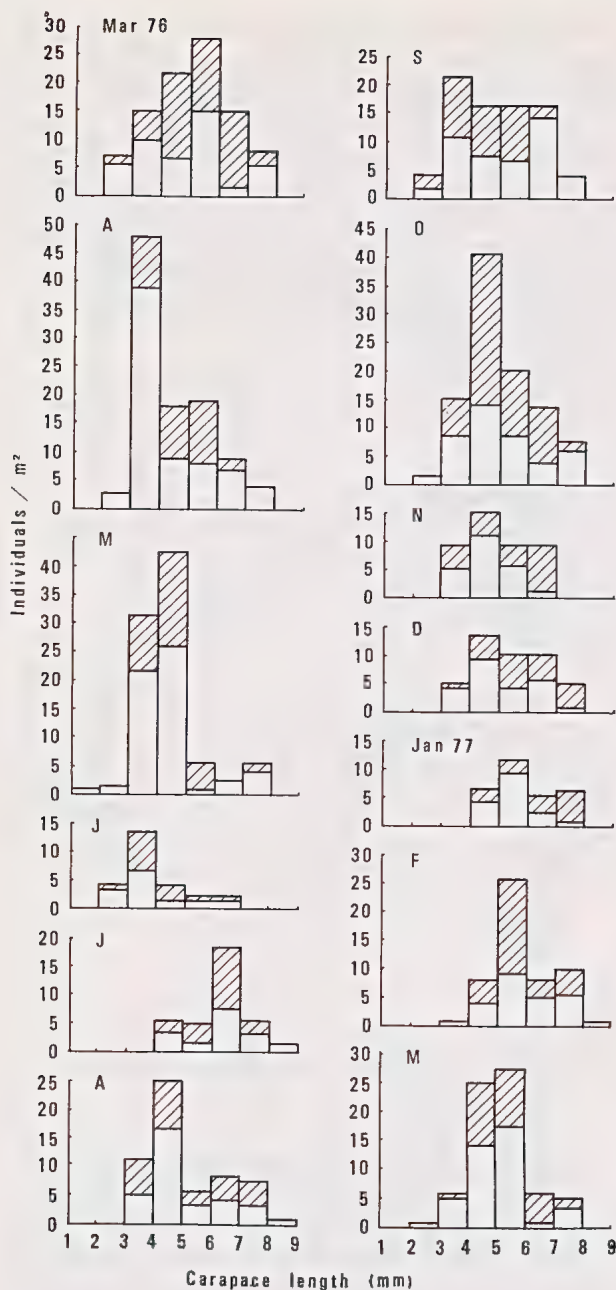


FIG. 4. — Size frequency histograms for *Callianassa arenosa* collected monthly from March 1976 to March 1977. Bar height indicates total individuals/m<sup>2</sup>; cross hatching indicates the number of females and the clear area number of males.

tion has been described for the terrestrial isopod *Armadillium vulgare*: small individuals produce one brood a year, large individuals two (Lawlor 1976).

For *C. australiensis*, the findings of this work are similar to those of other reports (Hailstone & Stephenson 1961; Robertson 1977) but differ in some details. Hailstone & Stephenson (1961) found the major breeding season of Queensland populations to be in autumn and the minimum size of spawning to be at carapace length 8-9 mm. The present work found most reproduction in spring and the minimum size for reproduction at 5-6 mm carapace length. In the present study, few ovigerous females were found after September although Robertson (1977) found that at Crib Point, 20 km south-west of the present study area, the major period of reproduction was October to December.

The virtual absence from the samples of reproductive individuals during the period October to January, although individuals elsewhere in the bay may be reproductive at this time, plus the appearance and disappearance of large non-reproductive individuals during these months, suggests the migration of *C. australiensis* through the study area. Migration was not directly observed, but has been reported for *C. turnerana* in the Cameroons (Monod 1927; *vide* Hailstone & Stephenson 1961), and for a number of other decapod species (Chittleborough 1970, Atkinson & Parsons 1973, Boddeke 1976).

#### ACKNOWLEDGEMENTS

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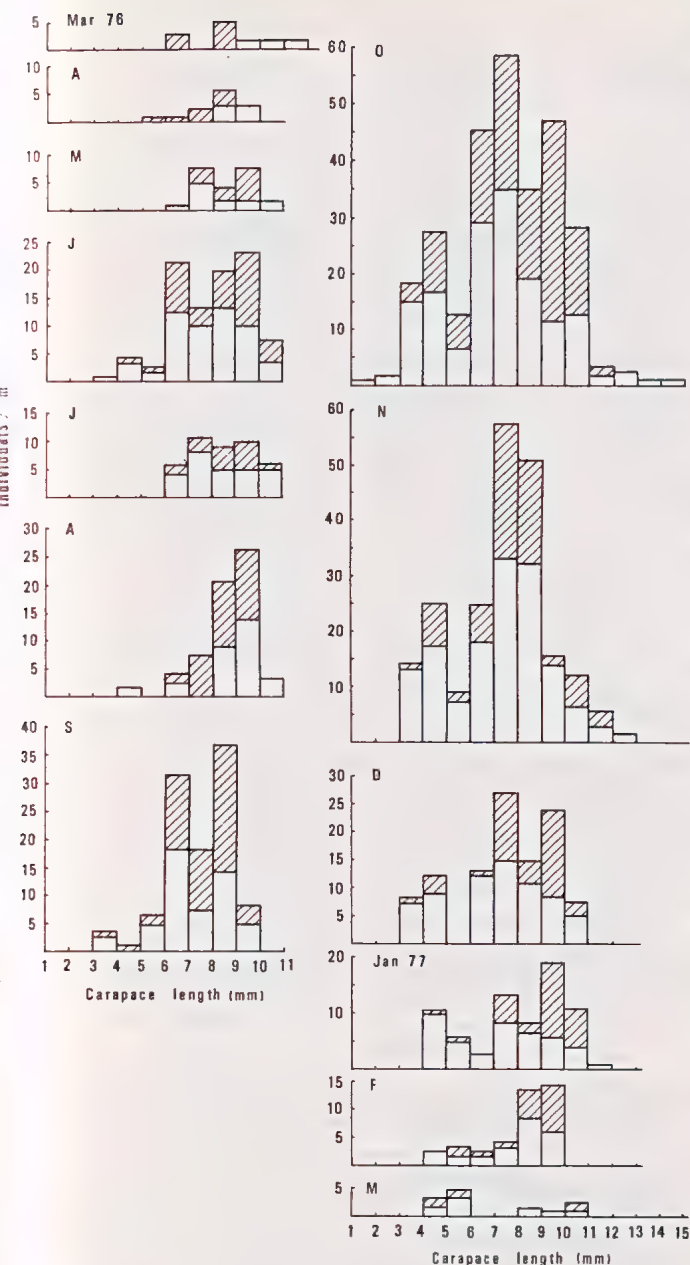


FIG. 5.— Size frequency histograms for *Callianassa australiensis* collected monthly from March 1976 to March 1977. Bar height indicates total individuals/m<sup>2</sup>; cross hatching indicates the number of females and the clear area number of males.

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## SHORT COMMUNICATIONS

### NOTES ON A FRAGMENT CORE AUSTRALITE

An unusual australite, having a fragment core, was recently discovered near Princetown, Western Victoria. The specimen is essentially complete and exhibits a triangular prismatic core with surrounding flange. The striking feature of the specimen is the core-flange interface which approximates three straight edges, indicating that the flange generation during entry through earth's atmosphere has taken place on a fragment of australite glass.

To the author's knowledge, the possibility of fragmentation of australites during flight has received no attention in literature. This is surprising considering the many australites known to be stressed and the force encountered during flight at hypersonic speeds (Baker 1946, 1958, 1959).

Stress within the mass of australite glass, with the application of external forces, may not be the only mechanism by which fragmentation is possible. For instance, the australite concentration within many strewnfields is very high, particularly in certain areas of Western Victoria, which implies that the probability of a collision between two masses of australite glass in flight, with resultant fragmentation, is also proportionately high.

By either mechanism, fragments of australite glass can be generated which themselves will be subject to the effects of the aerodynamic shaping process. If fragmentation occurs during the heating phase of flight, then the fragments produced have a limited time in which to form any further secondary effects. Australites so-formed will, in the majority of cases, therefore assume a shape which cannot be readily described by a standard classification.

The australite discussed in this paper is such a form. It was discovered by the author in August 1978, 10 km NNE of Princetown, Western Victoria. The specimen was found resting on its anterior surface in an eroded roadside gutter consisting of leached, sandy clay. Heavy rain on the day prior to discovery is thought to have dislodged the specimen from its original resting place.

#### DESCRIPTION OF SPECIMEN

The weight of the fragment core australite is 0.0484 gm and the specific gravity was determined to be 2.41 using distilled water at 20°C.

The specimen is essentially complete although a small circumferential chip has been removed from a portion of the surrounding flange. Having regard to the flange thickness in that section, the loss of weight due to the removal of the chip has been estimated to be less than 2% of the specimen's weight.

The anterior surface of the specimen, when viewed in plan aspect, is approximately ovoid in shape and is consistent with the anticipated features of an australite of similar mass and physical size. Minute bubble craters are evident on the surface together with shallow etched flow lines.

The posterior surface of the australite, when viewed in plan aspect, reveals several striking features. The prismatic core fragment has deeply etched flow lines which extend from the apex of the fragment, along the core faces and across the core-flange separation zone into the flange. Considerable contortion of the flow lines is evident in the separation zone at the vertices of the core, indicating that flange generation has taken place from the fragment.

Four bubble cavities are present on the surface of the prismatic core fragment, the largest being 0.4 mm in diameter. An examination of the specimen in transmitted light reveals an internal bubble cavity within the core of approximately 0.5 mm diameter. Smaller bubble cavities are also evident in the flange. A close examination of the fracture responsible for the removal

of the circumferential chip has revealed three partial bubble cavities which probably weakened the flange material in that section.

#### DISCUSSION

Complete australites so far brought to scientific notice, of weight comparable to the specimen described, are either disc, plate or bowl-shaped (Baker 1963, Baker & Cappadona 1972, Birch & Cappadona 1977). Australites of this type have no central core portion or, in some cases, a core portion which is insignificant in relation to the volume of flange material. Such core portions are invariably round or elliptical in outline.

In contrast, the specimen described here shows a disproportionately small flange in comparison to the central core mass which is essentially straight-sided in outline. On the basis of the core dimensions and the total weight of the specimen, it has been estimated that the core portion contributes some 70% of the specimen's total weight. This suggests that fragmentation of the parent body has taken place towards the latter stages of flight during the heating phase and that the generation of secondary effects has been limited by the remaining sculpturing time.

An important point to note in relation to the fragmentation of parent bodies and the aerodynamic sculpturing of the resulting fragments is that of flight orientation. Given that a fragment is produced in flight, regular secondary effects will only be evident on those fragments which can maintain a reasonably steady flight orientation. This implies a certain degree of symmetry of the fragment shape in order to prevent tumbling in flight (which would not produce any systematic development of a flange or similar features). The australite described had a symmetrical shape, a triangular prism, one face of which has been oriented in the direction of the flight path. Stable orientation during flight has been maintained by the symmetrical trailing surfaces which meet at a central apex.

#### ACKNOWLEDGEMENT

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FIG. 1—Plan view of the posterior surface of australite.

FIG. 2—Plan view of the anterior surface of australite.

FIG. 3—Oblique view of australite.

# SOME RECENT CHANGES IN THE FLORA AND AVIFAUNA OF RABBIT ISLAND, WILSONS PROMONTORY, VICTORIA

## INTRODUCTION

Rabbits were released on Rabbit Island as a food source around 1836 (Stokes 1846). More than a century later, in 1959, the island had an eroded area attributed to the presence of rabbits (Gillham 1961, 1962); however, the erosion might have been present in 1909 (Kershaw 1909). The rabbits had been affected by myxomatosis in 1965, when about 150 corpses were found. The use of carrots impregnated with '1080' poison (sodium fluoracetate) in 1966-67 apparently eliminated the remaining individuals since none have been seen since. Subsequently the area eroded diminished from 6.5 ha (16 acres) in 1965 to 0.6 ha (1.5 acres) in 1966 and has since disappeared. Revegetation in this area, initially and predominantly by *Senecio laetus* and then *Poa poiformis*, was assisted by prostrate species (e.g. *Carpobrotus rossii*, *Kennedyia prostrata*), and the total number of vascular plants recorded from the whole island increased after removal of rabbits. As the previously eroded area was stabilised and colonised by plants, so was it invaded by nesting Short-tailed Shearwaters *Puffinus tenuirostris* (see Norman 1967, 1970 for further details).

This note includes observations made on the island in 1978 (5 and 10 December) and 1979 (10 December).

## METHODS

Only specimens of the dominant plant species were collected in 1978 but in 1979 a more complete list of vascular species was compiled. A line transect was taken across the summit following a route used previously (figs 3-7 in Norman 1970); the percentage cover for each species present in contiguous 10-foot units was estimated. Photographs, for comparison with others taken between 1965 and 1968, were also obtained.

The distribution of shearwater burrows was determined by ground survey in 1978 when the island was divided into zones (Fig. 1). The numbers of burrows counted in circular quadrats (20 m<sup>2</sup>) placed semi-systematically throughout each zone were

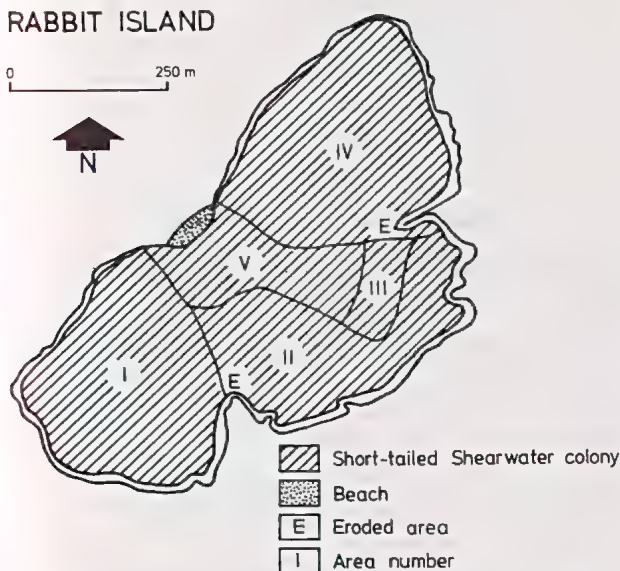


FIG. 1—Distribution of burrows of Short-tailed Shearwaters and areas used in density measurements, 1978.

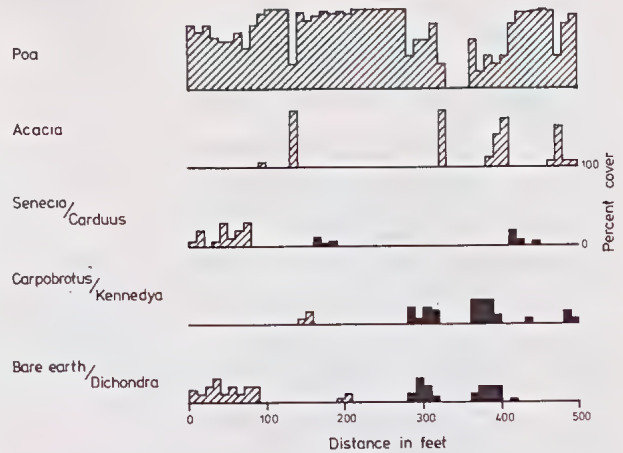


FIG. 2—Line transect, 10' units, showing percentage cover provided by major species; summit, peg to Trig. point. (Compare figs 3-7, Norman 1970).

used to provide mean burrow densities which when multiplied by area (determined from an aerial photograph by planimeter) gave an estimate of the population. No allowance was made for the sloping terrain.

No systematic search was made for burrows of Little Penguin *Eudyptula minor* but their approximate distribution was noted, and other bird species present were also recorded.

## RESULTS

### (i) Flora

Gillham (1960) recorded 24 vascular species, 4 of which were alien, from Rabbit Island. Between 1965 and 1968 a further 24 species were recorded, and during 1978 and 1979 specimens of another 15 species were collected (Table 1). A total of 63 vascular species (in 29 families) have now been recorded from the island; 14 of the species (22.2 per cent) are aliens (predominantly composites and grasses).

The lichens *Parmelia scabrosa* and *Teloschistes spinosus* were formally identified after our 1979 visit.

The beach region had changed markedly between visits in 1967 and those in 1978 and 1979. *Atriplex*, *Rhagodia* and *Tetragonia* had increased both in range and total area whereas *Cakile* and *Ammophila* had decreased (cf. Plate 15, fig. 1 with pl. 23 in Norman 1970). Behind the beach, and upwards towards the summit, *Rhagodia* had increased to invade some areas previously dominated by *Pteridium esculentum* or *Poa poiformis*.

More radical floristic changes were evident in the previously eroded area. In 1978 the number and size of the shrubs *Leptospermum laevigatum*, *Acacia longifolia* and *Leucopogon parviflorus* were a major feature of the island's central region where *Leptospermum* was most abundant. Within the *Poa* tussock community, more widely spaced here than elsewhere on the island, *Carpobrotus rossii*, *Acaena asnerinifolia*, *Lobelia alata*, *Kennedyia prostrata* and *Dichondra repens* were variously abundant. Bare areas had almost totally disappeared, except for a seasonally denuded area within a shearwater colony on the eastern side, and were vegetated by various species. In 1979 the transect (Fig. 2) demonstrated clearly the changes



TABLE 1  
LIST OF PLANTS COLLECTED IN 1959, BY GILLHAM (1961), BETWEEN 1965-8 (NORMAN 1967, 1970) AND IN 1978-1979.

	1959	Recorded in 1965	1965-1968	1978-1979
<i>Asplenium obtusatum</i>		+	+	+
<i>Microsorium diversifolium</i>		+	+	+
<i>Pteridium esculentum</i>	+	+	+	+
<i>Scirpus nodosus</i>	+	+	+	+
<i>Juncus pallidus</i>		+	+	sp.
<i>Bulbine bulbosa</i>		+	+	+
<i>Bulbine semibarbata</i>	+			
<i>Dianella revoluta</i>	+	+	+	
<i>Lomandra longifolia</i>				+
<i>Microtis unifolia</i>				+
* <i>Ammophila arenaria</i>	+		+	+
* <i>Hordeum leporinum</i>				+
* <i>Poa annua</i>			+	
<i>Poa poiformis</i>	+	+	+	+
<i>Stipa compacta</i>				+
* <i>Vulpia bromoides</i>	+			
<i>Carpobrotus rossii</i>	+	+	+	+
<i>Disphyma australe</i>	+	+	+	+
<i>Tetragonia implexicoma</i>			+	
<i>Tetragonia tetragonioides</i>		+	+	+
* <i>Carduus tenuiflorus</i>	+	+	+	+
<i>Cassinia aculeata</i>				+
<i>Cotula australis</i>		+	+	
<i>Cotula coronopifolia</i>	+			
* <i>Erigeron bonariensis</i>			+	
<i>Gnaphalium luteoalbum</i>				+
<i>Helichrysum dendroideum</i>			+	+
* <i>Hypochoeris radicata</i>				+
<i>Olearia axillaris</i>		+	+	+
<i>Senecio lautus</i>	+	+	+	+
* <i>Sonchus oleraceus</i>		+	+	+
<i>Cakile maritima</i>	+	+	+	+
<i>Wahlenbergia quadrifida</i>			+	sp.
<i>Spergularia media</i>	+			
* <i>Stellaria media</i>	+	+	+	
<i>Sambucus</i> sp.	+			
<i>Atriplex cinerea</i>		+	+	+
<i>Atriplex hastata</i>	+	+	+	
* <i>Chenopodium album</i>				+
<i>Rhagodia baccata</i>			+	+
<i>Dichondra repens</i>		+		+
<i>Crassula helmsii</i>			+	
<i>Crassula macrantha</i>				+
<i>Crassula sieberana</i>	+			
<i>Crassula</i> sp.			+	+
<i>Cyathodes acerosa</i>	+	+	+	
<i>Leucopogon parviflorus</i>				+
<i>Lissanthe strigosa</i>			+	
* <i>Centaurium pulchellum</i>				+
<i>Pelargonium australe</i>			+	+
<i>Lobelia alata</i>	+	+	+	+
<i>Acacia longifolia</i>	+	+	+	+
<i>Leptospermum laevigatum</i>		+	+	+

<i>Kennedyia prostrata</i>			+	+
<i>Pultenaea daphnoides</i>			+	
* <i>Trifolium dubium</i>				+
<i>Muehlenbeckia adpressa</i>	+	+	+	+
<i>Calandrinia calypttrata</i>	+			+
<i>Acaena anserinifolia</i>				+
<i>Correa alba</i>	+	+	+	+
<i>Solanum aviculare</i>				+
<i>Solanum laciniatum</i>		+	+	
* <i>Urtica urens</i>		+	+	+

which had taken place since 1968 (fig. 7 in Norman 1970). *P. poiformis* tussocks dominated the transect route, *Acacia* bushes (some taller than 3 m) were recorded for the first time and the importance of minor species, such as *Juncus* or *Kennedyia*, had declined. Changes are indicated by comparison of Pl. 15, fig. 2 with plate 23 (top) in Norman (1970).

Elsewhere on the island *P. poiformis* remained the dominant species. Occasional strands of *Solanum aviculare* and *Carduus tenuiflorus* covered small areas of shearwater colony as did *Senecio lautus*, though the latter had generally died back. A few bushes of *Correa alba*, *Acacia* and *Leptospermum* are now established around the island.

## (ii) Birds

Most Little Penguin burrows were found just above the shoreline around most of the island, and occasionally within the shearwater colonies. In 1979 most burrows examined held young, and dead birds were found throughout the breeding areas. The population, which may be about 200-500 burrows, does not appear to have altered in size since Gillham's (1961) record of 'many hundreds'.

Short-tailed Shearwater burrows were present wherever soil depth was suitable—indeed this must now limit their distribution on the island. The total numbers of burrows on the island was estimated at 131 000 (95% confidence limits 115 200-146 600; see Table 2). In 1959 many thousands of burrows were present, though there were none in the eroded area nor on the steeper cliffs (Gillham 1961). Some extension of the colony into the eroded area was apparent in 1968 and the expansion has continued since. In 1978 the total number of burrows for some of the area of the original sand blow (II, III and V in Fig. 2) was 44 600. A burrow density of 4/square yard

(3.7/m<sup>2</sup>), suggested by Norman (1970) for the eroded area, was not obtained during this survey. In only one quadrat did the density reach 1/m<sup>2</sup> and the average burrow density for the island was 0.5/m<sup>2</sup>.

Abandoned eggs were found frequently and, if the numbers of eggs present in quadrats were representative, may have totalled about 4000 for the whole island.

Eight adult and two young Cape Barren Geese *Cereopsis novaehollandiae* were present in 1978; 18 (including at least two juveniles) were counted in 1979 when non-flying goslings (one dead) and an old nest were found. Droppings were present over much of the island and clearly breeding pairs are now established, indeed S. G. Lane (*pers. comm.*) banded non-flying young on the island in November 1979. The species was not recorded by Gillham (1961); Dorward (1967) considered that the island was ignored by geese and none were seen there between 1965 and 1968.

Nests of Sooty Oystercatchers *Haematopus fuliginosus* (3), Silver Gulls *Larus novaehollandiae* (27) and Pacific Gulls *L. marinus* (5) were found in 1979.

The following species have also been recorded on the island: Black-faced Shag *Leucocarbo fuscescens*, White-faced Heron *Ardea novaehollandiae*, Whistling Kite *Haliastur sphenurus*, Marsh Harrier *Circus aeruginosus*, Peregrine Falcon *Falco peregrinus*, Brown Falcon *F. berigora*, Australian Kestrel *F. cenchroides*, Skylark *Alauda arvensis*, Welcome Swallow *Hirundo neoxena*, Fairy Martin *Cecropis ariel*, Richard's Pipit *Anthus novaeseelandiae*, Blackbird *Turdus merula*, Superb Fairy Wren *Malurus cyaneus*, Silvereye *Zosterops lateralis*, European Goldfinch *Carduelis carduelis*, Common Starling *Sturnus vulgaris*, Australian Magpie *Gymnorhina tibicen* and a corvid species. Most observations represent single sightings of transitory individuals and the paucity of resident passerine species is, presumably, due to the simple structure of the island's flora.

TABLE 2  
ESTIMATES OF NUMBERS OF BURROWS OF SHORT-TAILED SHEARWATERS ON RABBIT ISLAND IN DECEMBER 1978.

Area	Area (ha)	No. of quadrats	Burrow density/m <sup>2</sup>		Number of burrows	
			Mean	S.E.	Mean	Range
I	7.43	30	0.460	0.030	34 200	29 800-38 600
II	5.46	29	0.503	0.026	27 500	24 700-30 300
III	1.05	21	0.305	0.065	3 200	1 800- 4 600
IV	8.32	30	0.627	0.030	52 200	47 200-57 200
V	3.10	26	0.448*	0.035	13 900	11 700-15 900
Total					131 000	115 200-146 600

\*Possibly too low due to the difficulty of finding burrows among bushes.



## DISCUSSION

The revegetation of eroded areas on Rabbit Island, which followed shortly after the elimination of rabbits, was followed by an invasion of such stabilised areas by nesting shearwaters. The absence of rabbits (or their signs) during visits some ten years later (a period in which no fires were recorded on the island), and the dramatic development of the flora (both in size, cover and number of species), support the view that rabbits were effectively depressing the island's vegetation (Gillham 1962, Norman 1970) though drought may have affected species' availability during the earliest collection (Gillham 1961). Clearing of scrub on the island, presumably initiated before 1846, when the island was apparently occupied (Haydon 1846), was probably assisted by the frequent visits of 'birders' or 'egggers', from ship's crews and their passengers and of those seeking recreation, including rabbit shooting, there (Kershaw 1909, Lennon 1973, 1974, 1975). By 1909 the island had 'a little scrub', had 'dense bracken' in places, and was covered by tussocks (Kershaw 1909). In drier periods, rabbits probably further aggravated any erosion in shearwater colonies, and prevented regeneration. Additionally, the frequent landings, and selective grazing by rabbits, would have helped the introduction and expansion of alien plants and also decreased the abundance of sensitive native species. Certainly other Bass Strait islands (e.g. Clifly Island, Hope & Thompson 1971; Big Green Island, Norman 1966) which were occupied or grazed have more alien species than unoccupied islands. Burning of scrub and grazing by stock can also reduce the distribution of shrubs and modify or eliminate the *P. poiformis* tussock (e.g. in the Hogan Group, Scarlett, Hope & Calder 1974).

One factor influencing the vegetation on Rabbit Island has now been removed, and since 1966 the recovery and recolonisation of the eroded area has allowed expansion of the shearwater colonies. It will be of interest to monitor changes in the future. An increase in the complexity of the island's floristics may well allow the number of birds using the island, particularly passerine species, to increase.

## ACKNOWLEDGEMENTS

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## PLATE 15

Fig. 1—Beach on Rabbit Island, December 1979 showing areas dominated by *Atriplex*, *Rhagodia* and *Poa poiformis*. (Compare pl. 23 in Norman 1970).

## 2

Fig. 2—Fixed peg towards Trig. point, December 1979: dense *P. poiformis* backed by *Acacia* shrubs. (Compare pl. 23 in Norman 1970).





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1980

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## ABRIDGED REPORT OF THE COUNCIL FOR THE YEAR ENDING 6 MARCH 1980



Council has received with sincere regret the resignation of Mr. E. D. Gill from the office of Honorary Treasurer and from Council. Since he joined the Society in 1938, Mr. Gill has rendered outstanding services, as Honorary Secretary from 1956 to 1965 (including a period as Editor of "Proceedings"), as Honorary Research Secretary from 1966 to 1968, as President in 1969-1970 and as Honorary Treasurer from 1973 to 1979. He was awarded the Society's Research Medal in 1968, and was elected a Life Member *honoris causa* in 1974.

Professor A. B. Wardrop resigned in July from the office of Honorary Secretary which he had held since 1969.

### MEETINGS AND LECTURES

During the year, ten Ordinary Meetings were held.

MARCH 8—After the Annual General Meeting,

Professor B. H. J. McKellar delivered his Medal Lecture "What are the ultimate constituents of matter?"

APRIL 4—Dr. J. P. Wild, Chairman of CSIRO, spoke on "The Interscan Story".

MAY 10—Sir Charles Fleming, FRS, spoke on "Marine Biogeography and Evolution in the South Pacific".

JUNE 14—Dr. D. M. Calder spoke on "The Alpine National Park in Victoria".

JULY 12—Miss Kathleen Dugan spoke on "The Australian experience—a crisis for pre-Darwinian biology".

AUGUST 9—Dr. D. M. Churchill spoke on "The Royal Botanic Gardens and the National Herbarium".

SEPTEMBER 13—Symposium on "Energy". The speakers were Professor L. A. Endersbee and Mr. R. J. King.

OCTOBER 11—Symposium on "Victoria's Coasts and Continental Shelf" in honour of Mr. E. D. Gill. The papers presented are published in this Volume (92) of "Proceedings".

NOVEMBER 8—Soiree. Dr. D. F. Waterhouse spoke on "The history and future of biological pest control in Australia". Exhibits were displayed by the Keith Turnbull Research Institute, the Forests Commission of Victoria, the Plant Research Institute, Burnley, and ICI Australia Ltd.

DECEMBER 6—Dr. B. R. Wilson spoke on "Community studies on coral reefs at the Houtman Abrolhos Islands, Western Australia".

### MEMBERSHIP at 29th February 1980:

Honorary Life Members 4, Life Members 41, Ordinary Members 546, Associates 51, Suspense List (addresses not known) 13; Total 655.

Council recorded with regret the deaths of Mr. J. G. Baldwin, Mr. M. Brown, Dr. S. F. Cox, Dr. Irene

Crespin and Mr. A. C. Frostick (Life Members), Mr. Justice C. I. Menhennit (Trustee) and Mr. P. H. Woodhouse.

### RESEARCH MEDAL

The Society's Research Medal for 1979 was awarded to Professor M. J. D. White of the Research School of Biological Sciences, ANU, for a major and memorable contribution to cytogenetics.

### PROCEEDINGS

Publication of Volume 91 was delayed until mid-1980. Council acknowledges with gratitude the grant of \$3750 from the Government of Victoria and grants towards costs of publication from the Universities of Melbourne, Sydney, Adelaide and Tasmania; La Trobe and Deakin Universities; CSIRO; the Ministry for Conservation, Forests Commission, State Rivers and Water Supply Commission and National Herbarium of Victoria; the Water Resources Commission, N.S.W. and the South Australia Department of Agriculture and Fisheries.

### LIBRARY

1448 volumes and parts were received during the year from exchanges with 53 Australian and 280 overseas organizations. 556 items were borrowed from the Library (573 in 1978).

Capital donations to the Library Fund in 1979 totalled \$10,208, which Council acknowledges with gratitude. The invested capital of the Fund is now \$37,700, and the interest received in 1979 was \$3545.

### GENERAL ASSISTANT

Mr. R. Shirra died in March 1979. His place was taken by his daughter, Mrs. M. Lowe, who with her husband now occupies the Cottage.

### CONGRATULATIONS

Council congratulates Sir David Zeidler, Mr. C. W. Bonython, AO, and Dr. P. S. Lang, OBE, on whom honours were bestowed during the year.

### ACKNOWLEDGEMENTS

Council, on behalf of the Society, expresses its thanks to the many persons and organizations who have given valuable assistance during the year, including Mr. I. J. Curry, Honorary Auditor; Mr. D. Clarebrough, Honorary Financial Adviser; the Parks, Gardens and Recreation Department of the Melbourne City Council; and Mr. and Mrs. A. Lowe.

(s) L. L. STUBBS,  
President.

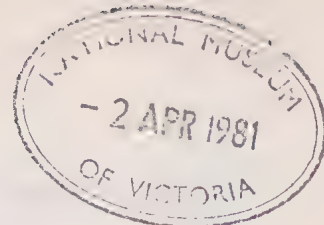












LIST OF MEMBERS AND ASSOCIATES, WITH THEIR YEAR OF JOINING, AT 31st DECEMBER, 1980

HONORARY MEMBERS:

BLACKWOOD, Sir Robert. MCE, BEE, MIE. 8 Huntingfield Road, Brighton, Vic. 3186.	1957
DEACOMBE, Major-General Sir Rohan, KCMG, KBE, CB, DSO, KStJ. Shrewton Manor, Shrewton, nr. Salisbury, Wiltshire, England.	1974
GILL, E. D. BA, BD, FGS, FRGS. 1/47 Wattle Valley Road, Canterbury, Vic. 3126.	1938
PESCOTT, R.T.M. MAgSc, FRES. 11 Peppin Street, Camberwell, Vic. 3124.	1944

LIFE MEMBERS:

AITKEN, Dr. Yvonne, DAgSc. School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052.	1936
ATKINS, Dr. C. M. BA, MB, BS. 74 Mi Mi Street, Oatley, N.S.W. 2223.	1964
BLACK, Mrs. J. Hope. MSc, Blue Mount A.I.S. Stud, Shinnick's Road, Baulkamaugh R.D, Numurkah, Vic. 3636.	1940
BONYTHON, C. W. BSc, Romalo House, Romalo Avenue, Magill, S.A. 5072.	1945
BROADHURST, E. MSc. 8/130 Balwyn Road, Balwyn, Vic. 3103.	1930
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BUTEMENT, Dr. W.A.S. CBE, DSc, MIEE, FInstP, 5A Barry Street, Kew, Vic. 3101.	1955
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COLLINS, A. C. Warwick Street, Herne Hill, Vic. 3218.	1928
COLLIVER, F. S. Geology Department, University of Queensland, St. Lucia, Qld. 4067.	1933
DOWN, Mrs. M. R. BAgSc, 177 Copeland Road East, Beecroft, N.S.W. 2119.	1942
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ESSERMAN, N. A. BSc, AInstP. 2/29A Stawell Street, Kew, Vic. 3101.	1923
FINCH, Dr. L. BArch, BSc, BAgSc, PhD, ANZIA, ARIBA. 27 Hawdon Street, Heidelberg, Vic. 3084.	1955
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GARRAN, Dr. R. R. MSc, PhD, FRSC, FRACI. 21 Bambra Road, North Caulfield, Vic. 3161.	1954
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CLAYTON, K.R. BSc. Scotch College, 491 Glenferrie Rd. Hawthorn, Vic. 3122.	1974
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